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Faculty of Engineering

PROBLEM SOLVING AND ENGINEERING DESIGN

INTRODUCING BACHELOR STUDENTS TO ENGINEERING PRACTICE

Christel HEYLEN

Dissertation presented in partial fulfilment of the requirements for the degree of Doctor of Engineering

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Dankwoord

'The rest of the team is necessary to judge and improve the quality of your own work'. Dit vertel ik onze eerstejaarsstudenten elk jaar bij de inleiding van P&O1 ('Probleemoplossen en Ontwerpen - deel 1', opleidingsonderdeel in de eerste fase van de bachelor-opleiding burgerlijk ingenieur aan de K.U.Leuven). Deze uitdrukking is ook van toepassing op mijn eigen doctoraatswerk. Dit was immers niet mogelijk zonder de hulp en inbreng van velen. Met veel plezier wil ik op deze eerste pagina's van mijn doctoraat de andere leden van 'mijn P&O-team' bedanken.

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Ik ben bijzonder fier en verheugd dat ik nu dit grote werk kan afsluiten en jullie mijn doctoraat kan voorleggen. *Op naar de volgende mijlpaal ...*

Hulshout, 27 juli 2010

Christel

Abstract

The world is changing and technology evolves rapidly. Besides a solid scientific and technical knowledge base, the present-day engineer, working in this international and increasingly complex knowledge society, needs a wide set of technical and social skills. The Faculty of Engineering at Katholieke Universiteit Leuven introduced a new engineering curriculum in September 2003. An integrated approach of science, technology and development of competencies makes the engineering studies more oriented to the current engineering profession and relates theory to practical technological applications already from the beginning of the curriculum. Besides teaching a broad base of scientific knowledge and educating very specialized technological knowledge and skills, more attention goes to developing creativity, interdisciplinary problem-solving skills and communication skills. Therefore a new course 'Problem Solving and Engineering Design' (P&O) was introduced, that takes a central position within all five years of the engineering study. From the first semester onwards a learning track is implemented to build up engineering skills.

Within this PhD work the instructional format for the course was developed and implemented for about 400 first year engineering students since September 2003. The P&O course of the first year has two main objectives: students need to integrate basic principles from the regular scientific courses to understand their coherence and relevance and they need to acquire technical and social skills that are important within the engineering profession (the ability to master new information independently; efficient use of ICT-tools; communication skills; a systematic approach to problem-solving and engineering design; simulation and experimentation skills; teamworking and project management skills; a creative and reflective spirit and critical attitude). P&O is a student-centred course, based on the concepts of active and project based learning. Active learning methods that are student-centred and hands-on, are very suitable for introducing design concepts, a key element of the engineering profession. By means of project work, learning can be centred around authentic engineering problems and students can learn how to work efficiently within a team.

For designing the course format, the scheme of the general educational concept of the K.U.Leuven, Guided Independent Learning, was used as a starting point. First a generic framework for the instructional format of the course was designed to help the students attain the learning goals. Because of the generic framework, it was possible to develop and implement two different sets of assignments for the project work within this thesis. Each set of assignments was situated within a challenging highly technological area that was related to the imagination of young engineering students and to their daily life by referring to the media as much as possible. Within the academic years 2003-2004, 2004-2005 and 2005-2006, the course was implemented around the technological theme 'aerospace engineering'. In the academic year 2006-2007 a second set of assignments was drawn up within another technological theme 'energy'.

Through the organisation of extensive student inquiries and interviews with the students and academic staff involved, the course concept is evaluated and optimised. With respect to the first learning objective of course integration, most of

the students indicate that they do apply the basic principles, taught in the regular courses, to complete the team assignments. However, fewer students are convinced to have learned more about these basic principles while working in team. So in future, the relationship between the project work and the regular coursework can still be improved. Regarding the second set of learning objectives, it can be concluded that the students do get gradually more skilled at technical and social competencies. Nevertheless, the experience tells us that without a reminder from the didactic team, students often forget about their previous experiences and make the same mistakes again. Forcing the students to work with the feedback helps to achieve the intended behavioural change.

By analysing multivariate data, the guidance of the teamwork, the learning effects and the team functioning are investigated more in detail. To gather these data the questionnaires contained multiple statements for each topic.

In project work, a lot of attention goes to the guidance of the students. Literature defines a number of responsibilities for the tutor of a student team: guidance of the team cooperation, guidance with respect to the content of the assignments, clarifying objectives and evaluation of the course, stimulation of self-activation and providing individual and team feedback. The study confirms the importance of providing clear information about the objectives and evaluation of teamwork and the significance of coaching the cooperation and team learning. However, in reality, often most of the time and effort goes to content-related guidance, because the students themselves urge continuously for content related help. The results of the study however reveal no correlation between the students' appreciation of this content-related guidance by their tutor and the perception of their learning. This might suggest separating even more clearly the content- and process-related guidance in future project work. In the current implementation, course specialists were already invited as experts. But it could be a possibility to make the daily tutors only responsible for providing information, guiding the problem-solving process and the team functioning, while the experts help the students with the scientific and technical content of the project assignment.

By re-allocating individuals to a new team at the beginning of each project we hoped to improve the socio-emotive quality (SEQ) of the new groups (the feeling they get on with each other). It was hoped that students could start again with a clean slate and bring in their learning experiences from former groups. However, the quality of groups neither did improve over the three periods nor was there any trace of transfer over periods. It thus seems that the SEQ of a group is not so much a function of what people have learned during former interactions. Rather it might be an index of something that is easier sensed than rationalised. Given that the SEQ of a group is hard to control and/or to alter, future research should focus on how to successfully cope with such defective SEQ-groups. In the context of an educational setting one possibility might be to re-assemble only groups with a bad SEQ once more.

In summary, this work shows the way the course 'Problem Solving and Engineering Design' is implemented in the first year of the bachelor of engineering, how it was evaluated and optimised to achieve the objectives. The results of this study are a strong foundation for the development of future project work and further educational research.

Samenvatting

Ingenieurs werken vandaag in multidisciplinaire teams in een internationale context waarin de technologie snel evolueert. Naast een goede wetenschappelijke en technische basiskennis, hebben zij daarbij nood aan technische en sociale competenties. De Faculteit Ingenieurswetenschappen heeft de hervormingen in het hoger onderwijs (invoering bachelor-mastersysteem, flexibilisering en internationalisering) aangegrepen om haar opleiding tot burgerlijk ingenieur grondig te vernieuwen. Het nieuwe programma koppelt sinds september 2003 wetenschap en technologie aan praktische toepasbaarheid en de opbouw van vaardigheden. De gekende troeven van de opleiding blijven behouden: een brede wetenschappelijke basisvorming gekoppeld aan een kwalitatief hoogstaande opleiding tot specialisten. Het nieuwe programma besteedt meer aandacht aan de ontwikkeling van creativiteit, probleemoplossend vermogen, vakoverschrijdend denken en communicatievaardigheden, en dit vanaf de eerste dag van de opleiding. Speerpunt van deze vernieuwing is de introductie van een nieuw opleidingsonderdeel: Probleemoplossen en Ontwerpen (P&O), dat als een rode draad doorheen de vijfjarige opleiding loopt. Vanaf het eerste semester wordt de theorie gekoppeld aan de technologie en praktijkervaring en worden ingenieursvaardigheden geleidelijk aan opgebouwd.

Binnen dit doctoraatswerk werd het didactische concept van dit opleidingsonderdeel ontworpen en geïmplementeerd in de eerste fase van de bacheloropleiding burgerlijk ingenieur. P&O heeft hier twee grote doelstellingen: de studenten moeten basisprincipes van de algemene wetenschappelijke en technische vakken integreren om zo meer inzicht te krijgen in hun samenhang en relevantie; en geleidelijk ontwikkelen ze technische en sociale vaardigheden die belangrijk zijn voor het ingenieursberoep (informatievaardigheden, modelleren en experimenteren, een systematische probleemaanpak en ontwerpmethodiek, communicatievaardigheden, kritisch reflecteren, creativiteit en leren werken in groep). De toegepaste onderwijsvorm stelt de studenten centraal. De eerstejaarsstudenten werken in groepjes aan authentieke projecten.

Het onderwijsconcept van de K.U.Leuven, Begeleide Zelfstudie, was het startpunt voor de uitwerking van dit onderwijsconcept. Eerst werd een generisch kader ontwikkeld waardoor de studenten de vooropgestelde leerdoelen bereiken. Zo was het mogelijk om tijdens dit werk twee verschillende sets van projectopdrachten uit te werken, binnen twee technologische thema's die motiverend zijn voor eerstejaars-studenten burgerlijk ingenieur. Tijdens de academiejaren 2003-2004, 2004-2005 en 2005-2006 werkten de studententeams aan opdrachten binnen het thema 'ruimtevaarttechnologie'. In het academiejaar 2006-2007 werd een tweede reeks van opdrachten geïmplementeerd, binnen het thema 'energie'.

Het P&O-concept werd geëvalueerd en bijgestuurd door de organisatie van uitgebreide studentenbevragingen. Met betrekking tot de eerste doelstelling, vakintegratie, bevestigt de meerderheid van de studenten dat ze basisprincipes van de andere wetenschappelijke vakken toepassen tijdens het teamwerk. Vakintegratie blijft echter een aandachtspunt, aangezien minder studenten geloven dat ze ook bijleerden over de andere vakken door hun P&O-project. In verband met

de tweede doelstelling kan worden besloten dat de studenten geleidelijk de vooropgestelde vaardigheden beter beheersen. Het is echter onze ervaring dat de studenten zonder nadrukkelijke herinnering, vaak hun vroegere ervaringen vergeten en telkens opnieuw dezelfde fouten maken. Studenten worden aangemoedigd om op basis van de gegeven feedback de gemaakte fouten te verbeteren zodat het een automatisme wordt.

Met behulp van multivariate data analyses werden de begeleiding van het groepswerk en het groepsfunctioneren meer in detail onderzocht.

Op basis van de literatuur werden de verschillende taken van de tutor van een team opgesteld: het begeleiden van de team-samenwerking, inhoudelijke begeleiding, de doelstellingen en het evaluatieproces verduidelijken, stimuleren van zelfwerkzaamheid en het geven van feedback. Het uitgevoerde onderzoek bevestigt het belang van het geven van duidelijke informatie over de doelstellingen en de evaluatie van groepswerk. Bij het begeleiden van projectwerk, gaat in de praktijk vaak de meeste tijd en aandacht naar het beantwoorden van inhoudelijke vragen van studenten. Er werd echter geen verband gevonden tussen de appreciatie van de studenten van deze inhoudelijke begeleiding en de perceptie van hun leren. Dit suggereert om in toekomstig projectwerk inhoudelijke begeleiding en procesbegeleiding strikter te scheiden. In de huidige implementatie worden reeds vakspecialisten uitgenodigd als experten. Een mogelijkheid is om de dagelijkse tutoren alleen verantwoordelijk te maken voor het geven van informatie en de procesbegeleiding, terwijl experten de studenten helpen met de wetenschappelijke en technische inhoud van hun project.

Bij het begin van elk semester worden nieuwe teams gevormd om de socio-emotieve kwaliteit (SEQ) van de nieuwe groepen te verbeteren (het gevoel dat ze goed met elkaar overweg kunnen). De studenten zouden zo met een schone lei kunnen beginnen en hun leerervaringen van de opeenvolgende semesters combineren. Het uitgevoerde onderzoek kon echter noch de toename van SEQ, noch de transfer van vroegere ervaringen bevestigen. Het lijkt er bijgevolg op dat de SEQ van een groep geen functie is van wat de groepsleden leerden tijdens vorige interacties. Het is eerder een aanvoelen. Aangezien de SEQ van een groep moeilijk te veranderen is, zou verder onderzoek zich moeten richten op de aanpak van groepen met een 'slechte' SEQ. In een onderwijscontext is het bijvoorbeeld mogelijk om alleen de studenten met een minder goede SEQ in nieuwe teams in te delen.

Samenvattend beschrijft deze tekst hoe het opleidingsonderdeel 'Probleemoplossen en Ontwerpen' in de eerste fase van de bacheloropleiding burgerlijk ingenieur werd geïmplementeerd, geëvalueerd en geoptimaliseerd om de vooropgestelde doelstellingen te behalen. De resultaten van deze studie vormen een stevig fundament voor de uitwerking van toekomstig projectwerk en verder onderwijskundig onderzoek.

Table of contents

1 Introduction

The world is changing and technology evolves rapidly. Besides a solid scientific and technical knowledge base, the present-day engineer working in this international and increasingly complex knowledge society needs a wide set of technical and social skills. He solves complex open-end problems in various contexts by creating products, processes or services, mostly in interdisciplinary teams. The Faculty of Engineering at Katholieke Universiteit Leuven introduced a new engineering curriculum in September 2003. An integrated approach of science, technology and development of competencies from the first year onwards makes the engineering studies more oriented to the current engineering profession and relates theory to practical technological applications already from the beginning of the curriculum. Therefore a new course 'Problem Solving and Engineering Design' was introduced, that takes a central position within all five years of the engineering study. From the first semester onwards a learning track is implemented to build up engineering skills. By means of project work, learning can be centred around authentic engineering problems and students learn how to collaborate in a team.

After motivating the introduction of the new curriculum, this chapter describes the instructional format of the course in the first year of the bachelor of engineering and situates it within the international literature.

1.1 Context: a new engineering curriculum

'Le métier de base de l'ingénieur consiste à poser et résoudre de manière toujours plus performante des problèmes souvent complexes liés à la conception, à la réalisation et à la mise en œuvre, au sein d'une organisation compétitive, de produits, de systèmes ou de services, éventuellement à leur financement et à leur commercialisation. A ce titre, l'ingénieur doit posséder un ensemble de savoirs techniques, économiques, sociaux et humains, reposant sur une solide culture scientifique.' (Commission des titres d'ingénieur, 2010)

> *'The profession of an engineer includes stating and solving often complex problems in a more and more decisive way. These problems are about the design, the realisation and to put into action products, systems or services, in the middle of an organisation in full competition – sometimes also the financing or commercialization of products, systems or services. In that capacity, an engineer should posses a large technical, economical and social baggage and insight into human nature, supported by a solid scientific culture.' (Commission des titres d'ingénieur, 2010)*

There are a lot of different definitions of engineers, and what their professional activities are. The definition above, stated by the French organisation 'Commission des titres d'ingénieur' is appropriate because it refers to the broadness of the engineering profession (the design, realisation and putting into action of products, systems and services), this engineering work is always done within a competitive context and furthermore reference is made to both knowledge and competencies, technical and social skills.

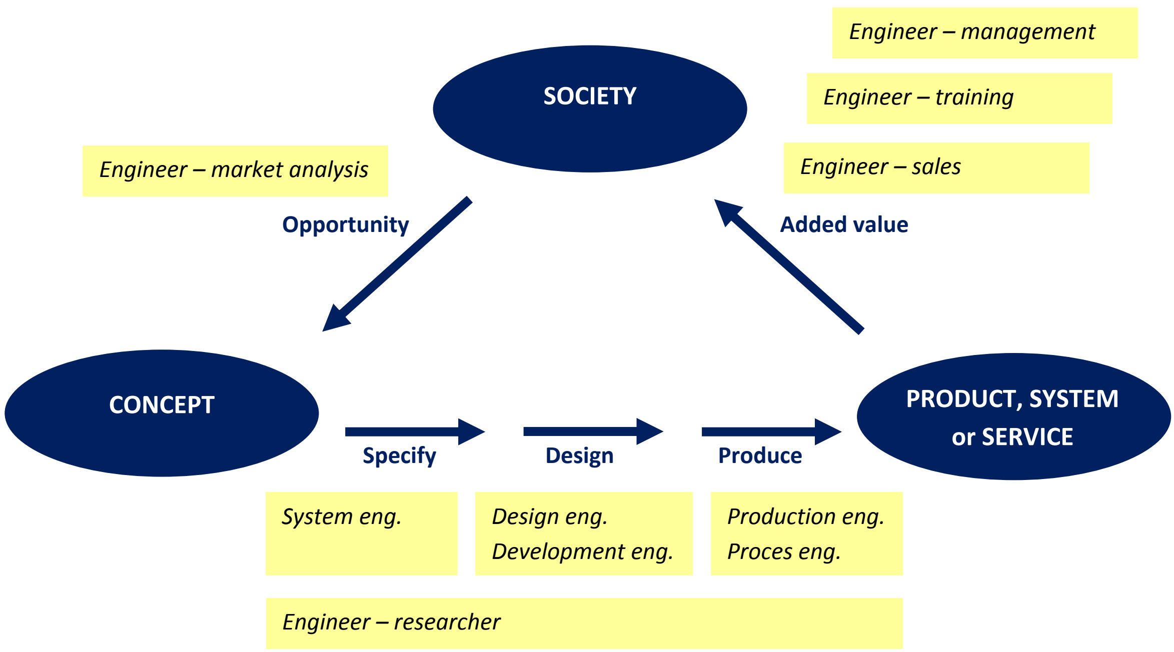

Figure 1-1. Multidimensionality of the engineering profession (Froyen, 2009).

Figure 1-1 shows the broadness of the engineering profession. Within all the steps of the life-cycle of a product, system or service, engineers are involved. The engineer-market analyst recognises an opportunity within society and translates it into a design-concept. The researcher will specify, design and produce the products, systems are services. And marketing-, training- and sales-engineers create added value in society. It remains however important to take into account the context of society. Therefore, the definition of the engineering profession will inevitably evolve.

The Faculty of Engineering at Katholieke Universiteit Leuven took the opportunity of the implementation of the bachelor-master structure to introduce a new curriculum in September 2003. An integrated approach of science, technology and teamwork was chosen to make the engineering studies more application oriented. In that approach more attention goes to creativity, interdisciplinary problem-solving skills and communication skills, besides teaching a broad base of scientific knowledge and educating very specialized technological knowledge and skills. Therefore, a new course 'Problem Solving and Engineering Design' was introduced, which takes a central position in all the five years of the new engineering curriculum.

The first three semesters of the bachelor program at Katholieke Universiteit Leuven are common to all engineering disciplines (with the exception of the study leading to the degree in architecture). The courses are subdivided into three groups: mathematics, energy and materials science, information and communication science. Parallel to the regular coursework, the students take the new course 'Problem Solving and Engineering Design' that introduces them from the first semester onwards into real engineering practice and teamwork. The aim of this course is to teach the students solving real life engineering problems requires the integration of different courses, which is supplemented with a gradual building up of technical and social competencies. For the majority of the time, the students work in small groups on interdisciplinary projects. Cooperative and active learning, together with a gradual building up of competencies are the didactic concepts on which the implementation of the project work is based.

The remainder of this chapter will describe the context that leads to the introduction of the course ‘Problem Solving and Engineering Design’ (‘*Probleemoplossen en Ontwerpen’* in Dutch, or ‘P&O’ in short). The objectives of the course will be situated within the international context of the engineering profession. Next the educational context is described to explain the terminology that is used.

1.2 Background and motivation

1.2.1 Introduction

This chapter will explain the ideas behind the introduction of the new engineering curriculum with the new course ‘Problem Solving and Engineering Design’ at K.U.Leuven in September 2003.

The introduction of the project based course situated within the context of our ever changing knowledge society. Engineers solve complex open-end problems in various international contexts, often in multidisciplinary teams. Therefore the objectives of engineering education have to evolve along those lines: besides relying on a firm knowledge base and technical competencies, the present-day engineers have to master communication and teamworking skills.

Furthermore the new engineering curriculum is situated within the context of internationalisation, as one results of the Bologna-agreements is the emergence of ‘academic profiles’ that state clear objectives for the academic curricula. Finally the Katholieke Universiteit Leuven puts forward one integrated educational concept: ‘Guided Independent Learning’. The course ‘Problem Solving and Engineering Design’ fits nicely within this concept that stresses the relationship between academic education and research.

1.2.2 Changing objectives for engineering education

Through fast ICT development and globalisation the world is changing and technology evolves rapidly (TREE Teaching and Research in Engineering in Europe, 2007). A few examples are nano-electronics, bio-electronics, sustainable technology and renewable energy, ecodesign... This is the territory of the engineer, where creativity and competence are of great importance. The engineer is an applied scientist, who solves problems in the society by creating products, processes or services. That way the engineer helps shaping the future. An engineer is a teamplayer who solves technical, scientific, economical, ... problems. He or she is polyvalent and has a scientific-technical interest. He loves to create.

Because of the increasing complexity of our ever changing knowledge society, present-day engineers need a wide set of technical and social competencies besides their solid base of scientific and technical knowledge (Bankel et al., 2003). They are required to solve complex open-end problems in various contexts, mostly in interdisciplinary teams. Therefore successful future engineers should possess at least two basic classes of competencies (Denayer et al., 2003): they should be able to solve complex engineering problems and they should know how to work in a team. The ability to direct their own learning process and assess their performance, together with interpersonal and social skills are recognized as essential objectives in today's engineering education (Bary and Rees, 2006; Lemaitre et al., 2006; Lundberg et al., 2003).

This international change of focus was confirmed by a recent Flemish study (Agoria, 2006). Agoria, the Belgian federation for the technology industry, performed a survey 'Skills for the future'. This survey dealt with the expectations of the Flemish companies regarding the competencies that engineers should posses in the year 2015. The results show that a firmly rooted technological knowledge base remains the most important element. Besides knowledge, a set of other skills are defined to be of high value for future engineers. Some of them were indicated as being the responsibility of the engineering curricula. These 'new' skills are the result of the trends in innovation. Knowledge evolves extremely rapidly. Therefore an engineer must be able to gather and master new information critically and to learn independently. Furthermore innovation is mostly the outcome of creative teamwork. Graduates need competence in project skills and creative thinking. Because organisations become more and more dynamic, engineers need to be competent problem-solvers.

1.2.3 The introduction of the Bachelor-Master's structure

Because of the Bologna Declaration of 1999, the Bachelor-Master structure was introduced in the higher education in Flanders. At the K.U.Leuven, the new programs in this BaMa structure were implemented year by year from 2004-2005 onwards (Verhesschen and Verburgh, 2004).

A working group defined educational 'profiles' that contain 'the most characteristic features of a programme'. These profiles describe the characteristic competencies of graduates necessary to get the degree (Werkgroep bamaprofielen van de associatie K.U.Leuven, 2003). These profiles stress the importance of competencies of a graduate: competencies being the integration of knowledge, skills and attitudes.

Based upon the Decree on the Structure of Higher Education (structuurdecreet, 2003), three groups of competencies are defined for a scientific academic bachelor programme. First there is a list of general competencies to ensure a general academic education; subsequently general scientific competencies and scientific competencies are defined. Table 1-1 gives an overview of the profile of the academic bachelor as it was translated by a working group of the Association K.U.Leuven (Associatie K.U.Leuven - Werkgroep Bamaprofielen, 2003).

Table 1-1. Overview of the competencies in the profile of the academic bachelor made by the working group of the Association K.U.Leuven (Associatie K.U.Leuven - Werkgroep Bamaprofielen, 2003).

	Competency-domain	**Competency**
General competencies	Thinking and reasoning skills	Being able to reason within the own discipline
	Information competencies	Being able to gather and assimilate consolidated information regarding the own discipline in Dutch and in another forum language
	Critical reflection	Being able to reflect critically upon the achievements and limitations of the own discipline
	Working project based and systematically towards creative knowledge-development	Confronted with 'new' problems within the own discipline, being able to retrieve existing answers or make an appeal to experts and systematically generate his own solution by combining existing answers
	Leadership	Being able to perform standard leadership tasks
	Communication skills: being able to communicate information, ideas, problems and solutions to experts and layman	Being able to communicate insights and methods of the own discipline written and orally, in Dutch and in another forum language with representatives of the own discipline, of other disciplines, or of the society
	An attitude of lifelong learning	Understand the limitations of the own discipline-bound competencies en willing to overcome them by education or self study

	Competency-domain	Competency
General scientific competencies	An investigative attitude and appreciation of the uncertainty, ambiguity and limitations of the knowledge	Being able to reflect critically upon the achievements and limitations of the own discipline
	Being able to employ research methodologies	Being aware of research methods and techniques and being able to employ them adequately
	Being able to gather relevant data to direct the judgement of social, scientific and ethical problems	Develop understanding and involvement in ethical and social problems in relation with the application of insights from the own discipline
	Being able to direct problem-based research	Confronted with 'new' problems within the own discipline, being able to retrieve existing answers or make an appeal to experts and systematically generate his own solution by combining existing answers
Scientific competencies	Understanding the basic scientific knowledge in a certain domain, systematic knowledge of the core elements of the discipline including the acquisition of coherent and detailed knowledge inspired by the latest developments within the discipline, understanding the structure of the field of study en the coherence with the other fields of study	Knowledge of scientific results that are situated in time and space including the research methodology of the discipline-bound results

1.2.4 Guided Independent Learning

The Katholieke Universiteit Leuven puts forward one fully-integrated educational concept, namely Guided Independent Learning (DUO/ICTO, 2008; Elen, 2003). This stresses the connection between research and education at the university. The university teaching is based on scientific research and it is beneficial for students to actively participate in ongoing research.

The Guided Independent Learning concept specifies objectives for university teaching, all strongly related to competencies transcending pure knowledge.

Furthermore the concept holds the students explicitly responsible for their own learning. The educational staff is responsible for providing adequate guiding for the students to attain the educational objectives. The concept of Guided Independent Learning does not impose a specific teaching method. It is rather a guideline that encourages teachers to consider all aspects of their educational practice and make coherent decisions to activate students and to support their work towards the learning objectives, use more interdisciplinary and authentic tasks.

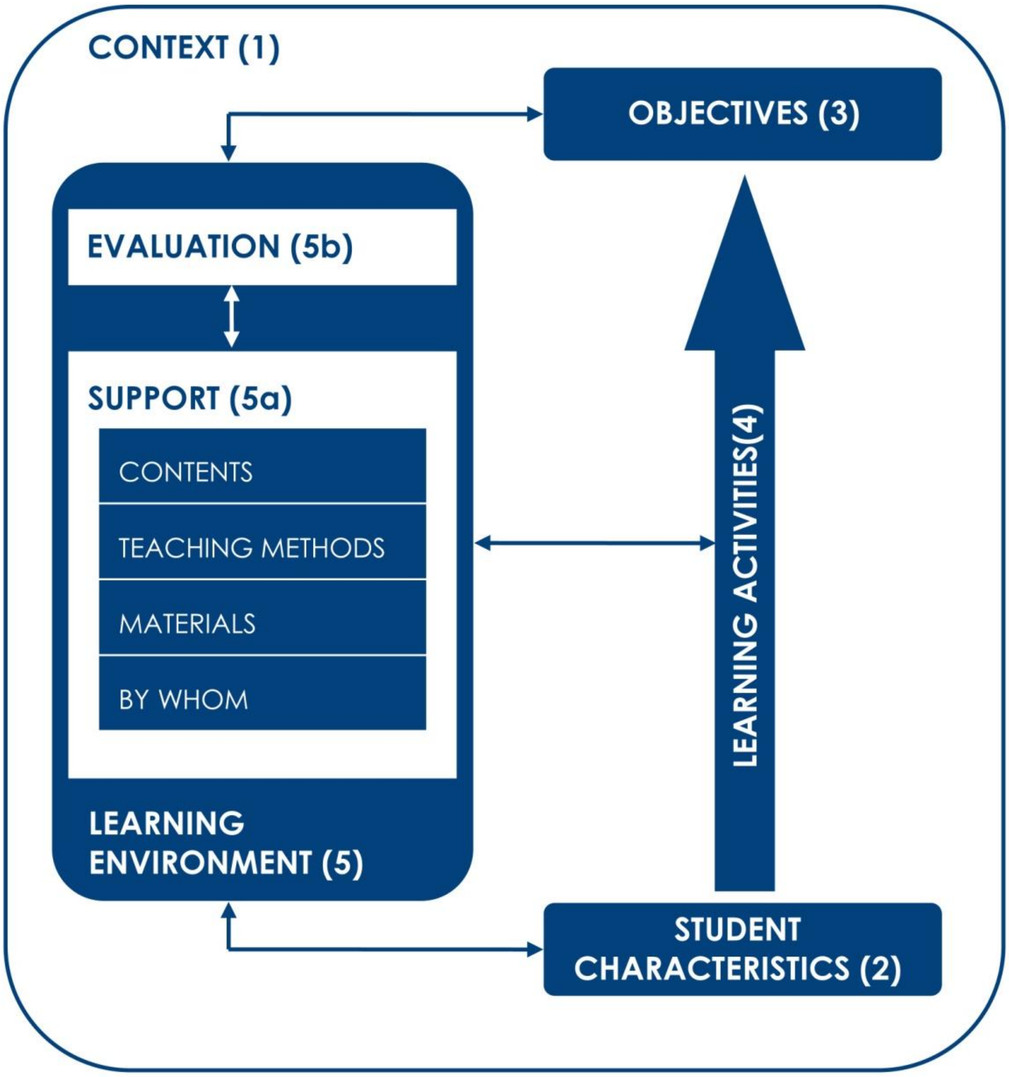

Figure 1-2. Schematic overview of the basic components of an educational practice and the relations between them (DUO/ICTO, 2008).

The schematic overview (Figure 1-2) shows all basic components of the educational practice. The Guided Independent Learning concept stresses the coherence between the components and the relations between them (DUO/ICTO, 2008).

(1) Each educational practice is situated within a certain context. The educational staff is limited in their decision-making by organisational preconditions (available rooms, available tools, available staff, etc.) and regulations (the academic schedule, the exam regulations, etc.).

(2) Students have different characteristics (prior knowledge, motivation, learning style, etc.). This variety of characteristics needs to be taken into account while implementing the learning environment and the support system.

(3) The educational staff states clear learning objectives for the course.

(4) Students must engage in well chosen learning activities to obtain the learning objectives. These learning activities are the core of the Guided Independent

Learning concept. The students are forced to take an active part in the education process.

(5) The educational staff provides a learning environment to stimulate the students engaging in appropriate learning activities and to support them in the realisation. A learning environment consists of two main elements:

(5a) The educational staff provides a support system to guide the students during their learning activities. Therefore they select learning contents, choose teaching methods, study materials and a variety of persons that are involved in the interactive teaching activities (professors, teaching assistants, other students). This support and guidance of the students decreases over time, while the students become gradually more autonomous learners.

(5b) The educational staff implements an evaluation system to verify to what extent the students attained the learning objectives. This is an important aspect of the educational practice. Students tend to adjust their learning activities according to the evaluation methods.

All these elements have to be geared to one another.

1.2.5 Socio-constructivism

The socio-constructivist view of teaching and learning emphasises cooperation. It considers learning to be the result of constructive activities from the students which are never purely individual acts (Elen and Laga, 2002).

Because a collaborative learning environment involves students actively in the learning process, educational theorists state that collaborative settings such as small project groups of co-learners are an effective means of learning, and they therefore play an important role in knowledge construction (Blumenfeld et al., 1996; Collins et al., 1989). By expressing ideas into words, by formulating opinions, by externalizing tacit knowledge, attitudes, approaches, values and perspectives, learners are expected to explore in more detail their own understanding (Johnson, 1971; Johnson, 1974), to generate more and better questions (Panitz, 2010) and to develop higher level thinking skills (Johnson, 1971; Vygotskij et al., 1978). Vague mental conceptualizations of an idea become internalized into more concrete representations (Resnick, 1993) resulting in a long-lasting, firmly rooted understanding (Kulik and Kulik, 1979). Because cognitive activities of learners become visible during group work, these activities also become subject to intervention and coaching. Hence, the externalized ideas of the learner provide a means for other learners and their teachers to react to, negotiate around, and build upon what they heard from the learner's side (Arias et al., 1999). Consequently, the conceptualizations of co-learners will gradually become fine-tuned and a common language and a common understanding - or a 'shared knowledge' - will be created (Scardamalia and Bereiter, 1993).

The above makes clear that within a socio-constructivist view on learning, both cognitive processes and social interaction are closely and intricately linked with each other (Doise, 1990; Doise et al., 1984). Social interaction and dialogue contribute to the construction of sound individual knowledge which in turn facilitates more sophisticated interaction and dialogue between learners.

Thus the students' own activities are crucial for the learning process, this is called student-centred instruction. Cooperation promotes the student's own learning by making his or hers own thinking process explicit and by the questions and contributions from others. That way knowledge is constructed within a certain socio-cultural context and the external support is emphasised.

In student centred instruction the teaching is concentrated around the students (Felder and Brent, 1996). When properly used, this approach enhances the students' motivation to learn, their retention of knowledge and depth of understanding and their appreciation of the subject (Felder and Brent, 1996; Johnson et al., 1998)).

The educational concept of the K.U.Leuven is a moderate form of socio-constructivsm. The student is active and constructs goal-oriented knowledge in interaction with an appropriate stimulating environment. Thereby he or she becomes more and more self-regulating and learns to organise his own learning process (Elen and Laga, 2002). The academic staff is responsible for organising the support system to bring about the necessary activities and learning processes that help the students to realise their learning objectives.

The general GIL-scheme (Figure 1-2) shows the main components of student-centred instruction and their coherence: the *students* – with their own *characteristics* like prior knowledge, motivation and metacognitive skills) are performing particular *learning activities* to attain the *learning objectives* and the *learning environment* to support the students for which the academic staff is responsible. Furthermore all teaching and learning is situated within its specific *context*.

The coherence between these components is important. The learning environment needs to be designed to support a particular student group with performing the learning activities that make it possible for them to attain the stated learning objectives. The support system takes into account the particular student characteristic and the evaluation system represents the learning objectives. The teaching methods focus on making the students aware of their own learning process and thinking strategies and incorporate the cooperative aspect of learning.

1.2.6 Discussion

The changing society, and therefore changing objectives for engineering education, together with the introduction of the Bachelor-Master's structure, urged the Engineering Faculty to implement a new curriculum, where the project based course 'Problem Solving and Engineering Design' takes in a central position.

This situates well within the international context of engineering education. As nowadays engineering curricula are paying more and more attention to competencies (next to a scientific and technological knowledge base), active instructional formats that are student-centred are being implemented (Lemaitre et al., 2006). By means of project work, learning can be centred around authentic and complex engineering problems and students can learn how to collaborate in a team.

The course 'Problem Solving and Engineering Design' in the first year of the Bachelor of Engineering at the K.U.Leuven is best described as student-centred instruction based on the concepts of active and project based learning. The course implementation fits within the socio-constructivist approach of teaching and learning, where students learn together in small groups. More specifically the educational concept applied is cooperative learning.

A working group of ten professors from the Engineering Faculty (G. Van der Perre, J. Vander Sloten, M. Smet, B. Blanpain, J. Vermant, J. Carmeliet, H. De Man, L. Roose, D. Reynaerts and S. Vandewalle) started in the summer of 2002 to write a syllabus for the new course. This working group also defined the necessary resources (educational staff and rooms needed), a rough time schedule and proposed a possible technological theme for the project assignments. In spring 2003 the new curriculum and the syllabus of the course were approved by the faculty and the first implementation started in September 2003.

At the start of the work for this thesis, a lot of attention went to the development and implementation of the course to reach the new objectives. The course development was based upon the proposals by the working group of the faculty and built upon previous experiences with project based learning and design-courses in the first year bachelor that were situated within the GIL concept (open-ended design project (Denayer et al., 2003) and concurrent engineering (Heylen *et al*. 2003).

After gaining experience, the thesis work became more research-oriented to further optimise the implementation characteristics. This fits within an international trend. In 2008 for instance, SEFI 'Société Européenne pour la Formation des Ingénieurs' or 'European Society for Engineering Education') started up a new working group 'Engineering Education Research' (SEFI - Société Européenne pour la Formation des Ingénieurs, 2008).

This thesis describes the course implementation as it is, based upon the experiences and adjustments within five implementation years. Because of our increasing experience and interest in engineering education research, the implementation of the course is dynamic and will be adjusted in the future according to new ideas, student feedback and research results.

1.3 Project based learning

1.3.1 Introduction

Project based learning organises learning around projects (Thomas, 2000). Projects are 'complex tasks, based on challenging questions or problems, which involve students in design, problem-solving, decision-making or investigative activities.'

While working on a project, students integrate previously acquired knowledge from different disciplines and work towards realistic end-products or presentations (Horváth et al., 2004; Thomas, 2000). There is a lot of emphasis on project management; each project has a clear start and deadline (Vos and Graaff, 2004). These deadlines close the gap between real-life and school environment (Gulbahar and Tinmaz, 2006). The teaching staff facilitates the problem solving, but the student teams work relatively autonomously and are encouraged to reflect upon their actions (Thomas, 2000).

Because of the use of authentic projects, the relation with real life problems motivates the students. Working on the project, students integrate knowledge from different courses and as such they experience the relation between theory and practice in multidisciplinary engineering problems. Moreover project based learning enhances thinking strategies, promotes a social learning environment and stimulates reflection and self-assessment (Clement et al., 2004).

Thomas evaluated research on project based learning approaches, considering all projects that (1) are central to the course, (2) focus on central concepts and principles of the discipline, (3) require acquisition of some new knowledge, (4) are student-centred and (5) are authentic. He discovered comparable or a bit better performance of students in project based learning on content knowledge tests and significantly better performance on conceptual understanding and problem solving, metacognitive skills and attitudes to learning (Thomas, 2000).

1.3.2 Project based learning in relation to problem based learning

Project and problem based learning are terms that are often mixed up and are used to address the same kind of instructional formats. For both terms the abbreviation PBL is used. Both methods organise learning around problems, which enhances students' motivation (TREE Teaching and Research in Engineering in Europe, 2007). However, literature reports however a small difference in the objectives and methods used.

Problem based learning is a student centred approach that enables students to conduct research and integrate theory and practice (Savery, 2006) . It organises instruction around ill-structured problems that provide a context for learning (TREE Teaching and Research in Engineering in Europe, 2007). Students gather and apply knowledge from multiple sources and disciplines (Hays and Vincent, 2004). Ill-structured problems have no easy answers, are rich in possibilities, promote a variety of approaches, require the application of diverse learning resources and show students their knowledge limits (Hays and Vincent, 2004). The main objective of problem based learning is to acquire and apply knowledge (Clement et al., 2004; Dochy et al., 2005).

In contradiction with problem based learning, *project based learning* is more focused on applying previously acquired knowledge and learning how to work in a team (Dochy et al., 2005). In project based learning approaches the students are usually provided with specifications for an end product and oriented towards following correct procedures (Savery, 2006).

1.3.3 History of PBL in engineering education

Problem based learning originated in medical education, to close the gap between theory and real world questions. It was first implemented in medical education in McMaster University in Canada in the 1960's, because one started to question traditional instruction methods because of the importance of experience and the application of theoretical knowledge for a physician. Furthermore the increased information accessibility and the explosion of knowledge give raise to a shift in the objectives from knowledge to real-world competencies like independent learning, problem-solving and decision-making skills (Oon, 2004). In 1968 problem based learning was first introduced in an engineering curriculum in McMaster University in Canada (where the introduction of PBL in medical education first started) (Barrows and Tamblyn, 1980). Subsequently, in 1972, PBL was implemented in the engineering programs of Linköping University, Roskilde University and Maastricht University. When PBL was first implemented in engineering education, based on the PBL implementation characteristics in medical schools, no attention went to the resulting product of the group work.

Because for engineering education in general, and engineering design in particular, the end-product is relatively important, Aalborg University implemented in 1974 a combined approach of problem and project based learning. In 1992 Maastricht University opted for a structured 7-step method that has similar characteristics as a design process. After all, this 7-step method demands from the students an analysis of the problem and the context, a problem definition and requirements; it stresses the importance of teamwork, team development and creativity and it is also an iterative process.

This describes the situation of existing PBL implementations in engineering until the early 1990's. All these universities opted for an institutional approach.

Nowadays the term PBL is used for a variety of practices, all situated within the context of problem and project based learning. Although there are differences, (Kolmos et al., 2009) described common learning principles in three areas: with respect to the learning, to the contents and socially. Related to the *learning* approach all PBL practices organise learning around problems to motivate the students. The learning will be carried out in projects with unique tasks and deadlines. The *content* of the learning is interdisciplinary and shows the relationship between theory and practice. Furthermore research methodologies are being trained. *Socially* PBL approaches are team based, the students learn through dialogue and communication. A particular PBL implementation can however never be copied to other universities (Kolmos et al., 2009). When implementing PBL learning principles the context of the social, cultural and educational traditions needs to be taken into account. The learning principles allow variation to adjust the instructional model to the given institution.

1.3.4 Active learning for introducing design concepts

Active learning approaches that are student-centred and hands-on have been shown to be effective teaching methods, especially when introducing design concepts (Kolb, 1984). 'Design requires the creative solution of open problems, the justification of solutions by technical analysis and the translation of these results into technical language in specifications, mathematical models and engineering drawings' (Edward, 2004).

Students learn more and different abilities which are needed to be competent practitioners (cognition, as well as metacognition) (Vos and Graaff, 2004). Active learning focuses mostly on metacognition. This entails the awareness and executive management of the student's own thinking, the ability to direct his own learning process and problem solving methods and assess his performance (Clement et al., 2004; Jones and Idol, 1990). Metacognition is an important aspect of student centred instructions, like Guided Independent Learning, the educational concept of the K.U.Leuven, and lifelong learning (Clement et al., 2004).

Learning through solving engineering design projects is an intensive form of stimulated active learning (Court, 1998; Horváth et al., 2004) and project based learning is a useful instructional method for teaching design concepts (Gibson and Van Strat, 2001; Horváth et al., 2004).

1.3.5 Small group learning

Project based learning is a particular implementation of small group learning. Small Group learning is an instruction method in which students work together in small groups toward a common academic goal (Gokhale, 1995; Johnson and Johnson, 1989; Tinzmann et al., 1990).

Nowadays, there is abundant evidence that collaborative learning has a lot of advantages for the knowledge construction of the learners involved. Students who collaborate in small groups on a common project have a lot of opportunities to present and discuss ideas, as well as to plan, organise and carry out activities related to the task at hand. Several authors attribute a long list of benefits to the richness and the diversity of these learner activities.

Students working in small groups tend to learn more of what is taught and retain it longer than when the same content is presented in a traditional instructional format (Davis, 1993; Oakley et al., 2004). By performing a study comparing group learning to individual learning, Gokhale concluded that group learning is more beneficial to enhance critical thinking and problem solving skills (Gokhale, 1995). Students get more new ideas and solutions to problems (Johnson and Johnson, 1989; Tinzmann et al., 1990), develop thinking and reasoning skills (Blumenfeld et al., 1996; Johnson and Johnson, 1989; Tinzmann et al., 1990), communication and teamworking skills (Oakley et al., 2004) and gain metacognition competencies (Johnson and Johnson, 1989; Tinzmann et al., 1990).

Moreover, small group learning promotes interpersonal and intergroup relations (Blumenfeld et al., 1996). Students are more intrinsically motivated and develop their intellectual curiosity (Johnson and Johnson, 1989; Tinzmann et al., 1990). They also appear more satisfied with their classes and show an improved positive attitude towards school (Johnson and Johnson, 1989; Johnson et al., 1991; Blumenfeld et al., 1996; Johnson et al., 1998). Because of that students are also less likely to drop out of school (Oakley et al., 2004). They gain a better understanding of the environment in which they will be working in their professional life (Oakley et al., 2004).

Conditions necessary to achieve benefits

Literature shows an ambivalent attitude towards group work (Clement et al., 2004): group learning has a lot of potential benefits, but it is also very vulnerable. When the groups are ineffective or dysfunctional, it could even be worse than individual learning (Oakley et al., 2004).

Realising the benefits of small group learning is dependent on the implementation characteristics of the group work. Several authors claim that it is most effective when it occurs in authentic contexts (Jonassen, 1991) and complex 'ill structured' domains (Spiro et al., 1988).

The importance of effective social interaction and team members possessing adequate interpersonal social skills in cooperative learning has been stressed (Johnson et al., 1990). Necessary skills are: project management, time management, conflict resolution and communication skills (Oakley et al., 2004). The students also need to learn effective group process skills. They need to learn how to reflect and evaluate the teamwork regularly (Johnson and Johnson, 1989; Tinzmann et al., 1990).

It has been recommended to create conditions that promote the development of a good intra-group socio-emotive quality, to install cooperative relationships between group members, to create a social environment where team members trust each other, where they feel 'they get on with each other', and where they experience a sense of community and social cohesiveness (Von Krogh et al., 2000).

1.3.6 Cooperative learning

Cooperative learning is 'a structured, systematic instructional strategy in which small groups work together toward a common goal' (Matthews and Cooper, 1995; Cooper and Mueck, 1990).

Two implementation characteristics distinguish cooperative learning from other small group instruction: there is a positive interdependence between group members and each student is individually accountable for his or her part of the work.

Cooperative learning is a form of small group learning, which is more structured and therefore sets off some of the weaker points of a collaborative learning environment. In cooperative learning the student's activities are well structured through the explicit interdependence between group members, interactive processes, responsibility and the building up of social skills like decision-making, communication and conflict management (Millis, 2002). The student group has a common goal, roles and tasks are being assigned to individual group members, each individual is held responsible for his or her learning, team-building activities are being organised and social skills, needed for effective group work, are being elaborated (Springer et al., 1999).

In contrast collaborative learning is characterized by relatively unstructured processes through which participants negotiate goal, define problems, develop procedures, and produce socially constructed knowledge in small groups (Springer et al., 1999). However, Kirschner stresses that both small group instructional formats have a lot of communalities (Kirschner, 2001). Both educational formats are implementations of active and small group learning. The teacher acts as facilitator, the students are responsible for their own learning and teaching and learning are therefore shared experiences between the teacher and the students. Both formats encourage the students to reflect upon their own thinking processes and provide opportunities for the students to develop social and teamworking skills.

Johnson et al. made a list of characteristics of cooperative learning (Johnson and Johnson, 1989). The student teams need to be formed carefully and heterogeneously; the teacher acts as a coach and a facilitator, not as expert; explicit attention goes to social skills and the emphasis is on face to face problem-solving.

To ensure a learning track within the course 'Problem Solving and Engineering Design', the bachelor students are gradually confronted with more demanding learning objectives. Throughout the first three semesters of the bachelor, a gradual transition from solving well structured closed engineering problems to working on open-end design projects is implemented. Gradually less instruction is provided and the students work more independently and organise their teamwork themselves. In doing so a transition from a more structured, cooperative approach in the first semester towards more independently collaborative working in the third semester is implemented.

1.4 Objectives and outline

The subject of this thesis is the development and implementation of the course 'Problem-Solving and Engineering Design' in the first year of the bachelor of engineering at the K.U.Leuven. The course has two main objectives, which are equally important. In the first place 'Problem Solving and Engineering Design' demonstrates the relevance and applicability of the basic principles taught in the regular scientific and technical courses. This should make the coursework more interesting and help the students master the abstract theories presented in lectures. The idea is that the students apply at least one basic theory of each regular course to complete the course project. Secondly during the first three semesters of the bachelor program, students are gradually confronted with demands that require more advanced technical and social skills:

- the ability to master new information independently;
- an efficient use of ICT-tools;
- communication skills: manual sketching techniques, object modelling using computer-aided-design software, writing technical reports and presenting their work orally;
- a systematic approach to problem-solving and engineering design;
- simulation and experimentation skills (simulation of the real world, design and set up of an experiment, data analysis, reflection and drawing of conclusions);
- teamworking and project management skills;
- 'engineering' attitudes: a creative and reflective spirit, critical attitude, accuracy, engagement and motivation.

The course 'Problem-Solving and Engineering Design' is a particular implementation of project based learning, it is a form of active learning that is student-centred and it runs through the whole five years of the engineering curriculum. In the first year of the bachelor the students take their first steps in the learning process, which will end in their fifth year with their master thesis.

The general hypothesis that will be addressed in this work is whether the particular implementation of project based learning that was developed and implemented in the course 'Problem-Solving and Engineering Design' in the first year of the bachelor of engineering at the K.U.Leuven results in attaining the objectives of course integration and gradual building-up of competencies.

The stated hypothesis can be translated into three main objectives:

1. Within this thesis the instructional format will be designed and implemented by which the students can attain the predefined learning objectives. The course has two main objectives: students need to integrate basic principles from the regular scientific courses to understand their connection and relevance and they need to acquire technical and social skills that are important within the engineering profession: the ability to master new information independently; efficient use of ICT-tools; communication skills; a systematic approach to problem-solving and engineering design; simulation and experimentation skills; teamworking and project management skills; a creative and reflective spirit, critical attitude, accuracy, engagement and motivation. For designing the course format, the scheme of the general educational concept of the

K.U.Leuven, Guided Independent Learning, was used as a starting point. The chosen implementation of the course 'Problem-Solving and Engineering Design' is a student-centred form of project based learning in which the students need to be active and work collaboratively in small groups.

2. The second objective of this work is to organise student inquiries to evaluate and improve the course concept. By means of this student feedback, together with the experiences of the staff involved, the course implementation is evaluated to discover whether the course objectives were attained. Based upon the results, the instructional format was optimised during the subsequent implementation years.

3. Particular aspects of the instructional format will be analysed more in detail. Mainly the guidance of the students, the relationship between the guidance and the student learning goals and the socio-emotive quality of the students' teamwork will be evaluated. The questionnaires are composed by using multiple items (questions) measuring each topic. By using a factor analysis the actual scales can be computed based upon the data. The results will be redirected to the implementation practice and recommendations for future improvements will be made.

The first objective will be discussed in chapter 2 *Implementation*, and chapter 3 *Actual implementation within two different technological themes*. Chapter 2 describes the generic principles of the implementation of the course; this is the framework in which the students work on particular assignments that can vary according to the academic year. In chapter 3 two sets of actual assignments are described, that are implemented in the academic years from 2003-2004 until 2006-2007.

Chapter 4 *Evaluation of the course concept* addresses the second objective. It describes the organisation of the student questionnaires and the main results.

Chapter 5 *The relationship of guidance, perceived learning effects and socio-emotive group quality* describes the analysis of the student guiding in relationship to their learning and discusses the socio-emotive quality of the teamwork.

Chapter 6 of this thesis draws the conclusions and offers some future perspectives.

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2 Implementation

This chapter describes the generic implementation characteristics of the course 'Problem Solving and Engineering Design' by which the first year students attain the predefined learning objectives. The instructional format is project based learning with course integration and gradual building up of 'engineering' competencies as equally important learning objectives. Because of the variety of objectives different teaching methods are integrated. Lectures accompanied by exercises in small groups introduce technical skills. After that teamwork starts: for the majority of the time the students work in small groups on project assignments within one technological theme. This chapter explains the context and student characteristics, the learning objectives and learning activities and the assessment process of the course.

2.1 Introduction: specific didactic principles

2.1.1 Project based learning

The implementation of 'Problem Solving and engineering Design' in the first year of the bachelor can be situated in the six elements characterising Project Based Learning (Dekeyser and Baert, 1999) (Figure 2-1).

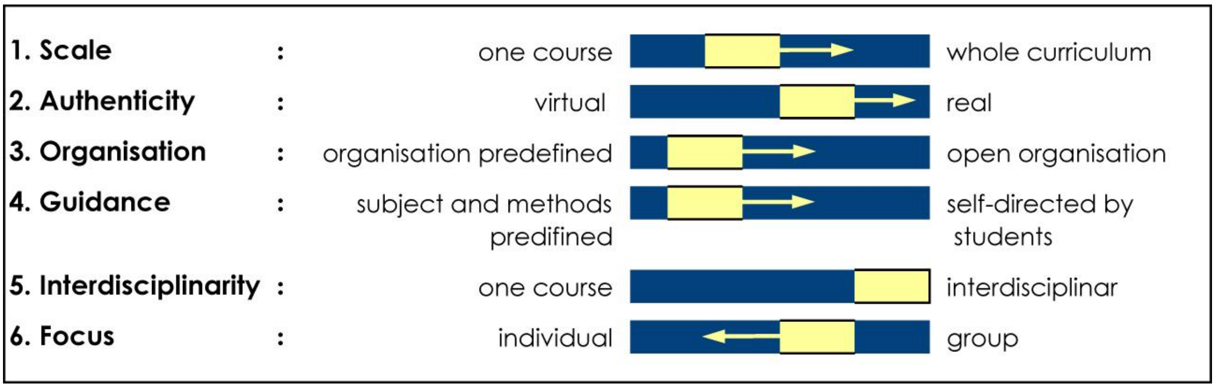

Figure 2-1. The figure situates the course 'Problem Solving and Engineering Design' of the first year of the bachelor of engineering on six implementation scales for project based learning mentioned by Dekeyser and Baert (1999). The arrows show the learning track within the course of the engineering curriculum.

1. *Scale:* Project based learning is implemented within one course of the curriculum. However this course takes in a central position, because there is an interaction with all other scientific and technical courses. During the engineering curriculum gradually more time is reserved for projects throughout the five years.
2. *Authenticity:* To motivate the students the assignments are as authentic as possible. The project work of the first year is situated within a technological theme which is introduced to the students by experts. Because the course is programmed in the first year of the engineering study, a lot of real situations need to be simplified to make them controllable for the students.
3. *Organisation:* Within the project work a learning track is implemented over time. In the beginning the organisation of the teamwork is defined by the didactic team. Learning to work efficiently within a team and to organise the work is one of the learning objectives of the course. Students become gradually more responsible for their own team organisation.
4. *Guidance:* The subject of the assignments and the problem solving methods are also predefined by the didactic team. Because the integration of different courses is an important learning objective, together with all technical skills, the assignment is carefully designed to encompass all objectives and build them up gradually to provide a learning track.
5. *Interdisciplinarity:* The integration of different courses is an important objective.
6. *Focus:* The main emphasis is on the team work, but individual contributions and individual learning goals remain important and will be evaluated individually.

2.1.2 Course integration

By integrating the regular scientific courses, the first year students are confronted with the relevance and applicability of the basic theories presented in the lectures. Demonstrating the relationship between the theoretical principles and the engineering practice is assumed to make the coursework more interesting and (ultimately) encourage the students to study their regular courses. The project assignments are as authentic as possible and emphasise explicitly the technical applications of basic theories. In the regular lectures the professors use occasionally real life examples that are situated within the context of the project.

Additionally students are experience the coherence between the different scientific courses. They realise that solving real life engineering problems requires the integration of different courses. In general one of the criteria for the selection of the problem of the project, is that students will have to apply at least one basic principle of each regular scientific course.

2.1.3 One technological theme

The bachelor students work on projects situated in a technological and challenging context (Millis, 2002; Ringwood et al., 2005). The theme is selected for its benefit of technology into the society. To bridge the gap between the theoretical lectures and the real world, the projects are as practical and visually stimulating as possible.

The technological theme should appeal to the eighteen year old students. This is achieved by selecting a state of the art theme, with some attention by the media. In doing so, the project shows the implications of the engineering study in the social environment of the students.

Because of the explicit objective of 'Problem Solving and Engineering Design' to integrate all regular courses, the technological theme has to be chosen well.

The assignments of the first semester consist of closed calculations within the broad technological theme. This is supplemented with an experiment to make the students familiar with making a numerical model, performing scientific experiments, processing data and draw critical conclusions. The scientific courses that need to be integrated are mathematics, calculus, mechanics and chemistry.

The project of the second semester focuses on a practical design assignment within the same technological theme. This makes the project more tangible and practical. The students can use the general calculations they made in the first semester and apply them to the more specific design case.

During the last five years two sets of assignments were developed, situated within two different technological areas: 'aerospace engineering' and 'energy'. A detailed elaboration of the themes and the corresponding assignments are described in chapter 3 *Actual implementation within two different technological themes*. The generic aspects of the assignments and the relationship between the learning activities and the learning objectives will be discussed in the remainder of this chapter (chapter 2 *Implementation*).

2.1.4 Gradual building-up of competencies

The P&O-courses of the first year provide the first step in the learning track that runs through all five years of the engineering curriculum. In the second year all students take again a P&O-course where they work in teams of six students on an open end design project. The outcome and solution strategies are less defined and the students organise their teamwork themselves. In the third year of their education, most students (depending on their major and minor) work on a P&O project. Gradually throughout the years, the project work takes a more important position within the curriculum. Finally the master thesis is the final project (with 24 ECTS credits), where students demonstrate their engineering skills.

The bachelor students are gradually confronted with more demanding learning objectives, ensuring a learning track. Throughout the first three semesters of the bachelor, a gradual transition from solving well structured closed engineering problems to working on open-end design projects is implemented. In the first semester, the students work on well-defined closed engineering problems, the assignment of the second semester consists of a closed design project and in the third semester the teams work on an open-end design project. This thesis work focuses on the P&O courses of the first and second semester.

A competency is the ability that enables students to recognize and define new problems within their domain of study as well as to solve these problems (Kirschner, 2001). A competency is therefore a combination of complex cognitive and higher-order skills, highly integrated knowledge structures, interpersonal and social skills, attitudes and values. Within the course of this work 'technical competencies' refer to this highly integrated mixture of knowledge, technical skills and attitudes. They encompass course integration, efficient use of ICT tools, information skills, modelling and experimenting and systematic problem solving. Social skills (communications skills and teamworking skills) and attitudes (critical reflection, independence, responsibility, accuracy and creative spirit) are stated separately.

Short just-in-time lectures inform the students about skills and attitudes that they should work on, explaining the importance of the competencies. Students first get an extensive instruction, and then use the competency while working on the assignment. After receiving feedback from the didactic team, students are encouraged to reflect upon their progress based on that feedback to correct their errors. In later assignments students are reminded of previous tasks concerning the same competency. That way, less instruction is needed and students can work gradually more independently.

2.1.5 General overview of the chapter

For designing the course format, the scheme of the general educational concept of the K.U.Leuven, Guided Independent Learning (GIL, Figure 1-2), was used as a starting point. First the context of the course within the curriculum of the students will be described (paragraph 2.2) together with the student characteristics (paragraph 2.3) and the learning objectives (paragraph 2.4).

Paragraph 2.5 explains the learning environment together with the corresponding learning activities of the students by which they can attain the previously mentioned learning goals. Because of the variety of aims, different instructional formats are integrated within 'Problem Solving and Engineering Design'. Each semester starts with introductory lectures, explaining the concepts of the course. In the first part of the semester instruction lectures introduce certain technical skills. These lectures are accompanied by exercises in small groups of about 30 students, to give each individual student the opportunity to practice. The acquired skills will be used later on during the teamwork. In the second part of the semester teamwork starts. Engineering lectures discuss more in detail the application of technical skills. They are programmed just in time and as short as possible. Where possible experts are invited to give the students a broader perspective on the engineering profession and provide detailed content information.

Figure 2-2 and Figure 2-3 give an overview of the two semesters and indicate the relationship between the learning activities and learning objectives. The course implementation is best described as project based learning, where students work together in small groups for most of the time. This chapter focuses on the generic aspects of the course implementation, which are based upon the recommendations in literature and previously acquired experience with project based learning and design-courses in the first year bachelor that were situated within the GIL concept (open-ended design project (Denayer et al., 2003) and concurrent engineering (Heylen et al., 2003). Within this generic framework the assignments themselves can vary relating to a particular technological theme.

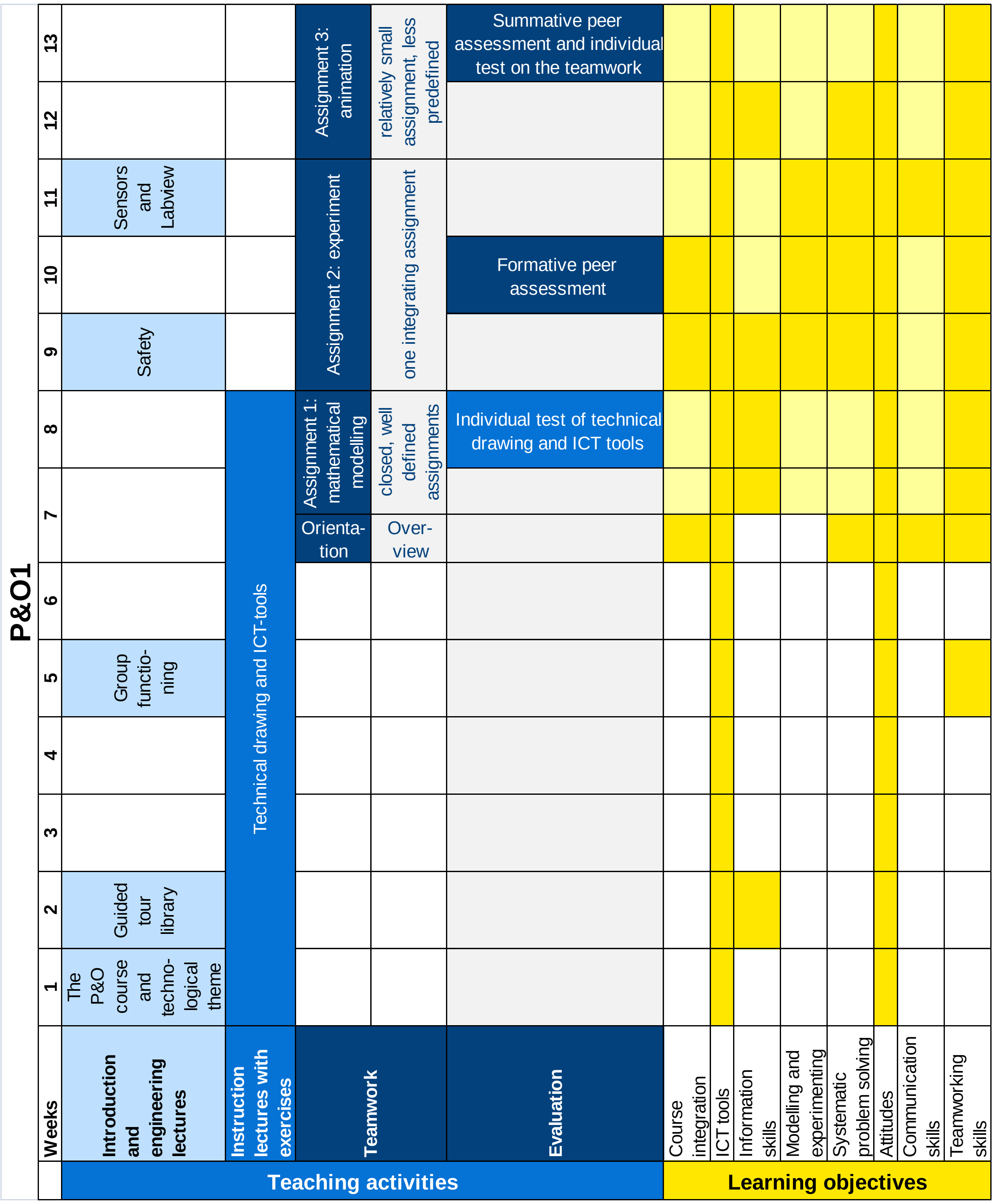

Figure 2-2. Overview of the learning activities in relation to the learning objectives of the course 'Problem Solving and Engineering Design' in the first semester, P&O1.

P&O2

	Teaching activities				Learning objectives							
Weeks	**Introduction and engineering lectures**	**Instruction lectures with exercises**	**Teamwork**	**Evaluation**	Course integration	ICT tools	Information skills	Modelling and experimenting	Systematic problem solving	Attitudes	Communication skills	Teamworking skills
1	Project planning and design methodology	Modelling objects (CAD) and processes (FSM)										
2												
3												
4	P&O2 team assignment and communciation skills		Closed design project	Individual test of modelling objects and processes								
5												
6	Mechanical and electronical parts											
7												
8				Formative peer assessment								
9												
10												
11			Demon-stration									
12												
13			Presen-tation	Summative peer assessment and individual test on the teamwork								

Figure 2-3. Overview of the learning activities in relation to the learning objectives of the course 'Problem Solving and Engineering Design' in the second semester, P&O2.

2.2 Context

The course 'Problem Solving and Engineering Design' is implemented within each semester of the curriculum. The courses gradually build up the engineering competencies throughout all five years of the study (ending in the master thesis). Because of the explicit learning objective of course integration P&O has also a very central position within the first year of the bachelor. There is an interaction with all other scientific and technical courses: in the teamwork the students apply basic principles they are taught in the regular courses, and in the regular courses examples are often situated within the technological theme of the project work. This central position is reflected within the ECTS study points of the course: 4 ECTS study points in the first semester and 3 in the second semester (out of 30 ECTS study points for a whole semester).

A limiting condition for the course implementation is the number of students that take the course. In the first year the course is compulsory (400 to 500 students). Because of this large number of students, the organisation requires a lot of effort. The teamwork is organised within a design room that is available for 120 students each afternoon. The staff available for organising the course and guiding the students is limited.

Two staff members are occupied by the daily coordination, three teaching assistants work half time to coach the students for the teamwork and one half time technical co-worker assists the students while making their design products and performing experiments. Furthermore teaching assistants, related to the regular courses, are invited as experts to explain more in detail the use of the basic principles taught in the scientific courses.

2.3 Student characteristics

The Problem Solving and Engineering course discussed in this work is programmed in the first and second semester of the bachelor of engineering at K.U.Leuven. The attending students finished high school. Since the entrance exam was abolished in 2004, the growing heterogeneity among the student population of characteristics such as prior knowledge and prior skills, has to be taken into consideration while implementing the course.

2.4 Learning objectives

In the GIL-scheme it is essential that clear learning objectives are stated for the students. These objectives include the mastering of technical competencies (integrate basic scientific courses, efficient use of ICT tools, information skills, modelling and experimenting and systematic problem-solving), emphasise students' attitudes and social skills (communication and teamworking skills). These objectives are important for the engineering profession and reflect the academic bachelor profile and the general objectives for academic graduates of the K.U.Leuven. Table 2-1 summarises the learning objectives for the course in the first and second semester. The objectives are stated as concrete and clear as possible and are communicated clearly to the students. In the table the learning objectives of the second semester are highlighted in grey. This reflects the gradual building up of competencies during the first year of the bachelor.

Table 2-1. Learning objectives for the course 'Problem Solving and Engineering Design' in the first year of the bachelor of engineering. The objectives highlighted in grey are introduced only in the second semester.

TECHNICAL COMPETENCIES

Course integration

- Realise that solving real-life technical problems requires the integration of different scientific and technical courses.
- Apply the basic principles taught in the scientific and technical courses in a proper manner.
- Content of the assignments: understand the application of the basic principles (understand which theory you apply and why that is appropriate) and be able to use these theories again in likewise problems.

Efficient use of ICT-tools

- Efficient use of Maple, spreadsheet (MS Excel), word processing (MS Word), MS PowerPoint en WWW (MS Internet Explorer).
- Give a clear name to computer files and a logical structure.
- Organise computer files in a logical manner.
- Consult the electronic learning environment, Toledo, at a regular basis, i.e. at least twice a week.

Information skills

- Be able to look up requested information in the library and on the Internet.
- Take into account the dependability of information sources.
- Understand new information and be able to apply it solving a new problem.
- Analyse new information, summarise a problem and point out the most important aspects.

Modelling and experimenting

Modelling

- Model the reality based on current knowledge by proposing hypotheses.
- Get first a global idea of a problem starting from a very simplified model of the reality. Afterwards you can make this model gradually more complex.
- Value this three subsequent steps:
- 1) calculation: model the reality;
  2) validation of the model based on literature and/or an experiment;
  3) reflection: formulate a conclusion.
- Be able to model a process using Finite State Machines.

Experimenting

- While doing an experiment, take safety into account and formulate a risk analysis.
- Adopt a critical attitude towards measured data:
    - which variable is measured?
    - how can you calculate the requested variable starting from the measured one?
    - is the measured data like you expected it, taken into account the circumstances of the test?

Systematic problem-solving

- Work systematically while solving a problem and use the seven step procedure (TSM - Teaching & Schoolmanagement consultants, 2010).
- Use a scheme to structure ideas.
- Plan the necessary work by using a project planning (draw up a task structure, responsibility chart, calendar with deadlines and a gant-chart).
- Engineering design: use a systematic approach for designing.
- Use a budget for designing.

ATTITUDES

- Reflect critically:
  - on the progress of the teamwork with respect to the content of the assignments
  - on your individual results on the course objectives (by using an individual logbook)
  - Reflect critically =
  - State clearly the achieved results
  - Judge the value and accuracy of the achieved results
  - Point out weaknesses
  - Give explanations
  - Propose solutions.
- Work independently
- Work accurately
- Act responsibly
- Creativity

SOCIAL SKILLS

Communication skills

- Explaining ideas by means of a manual sketch
- Being able to read technical drawings
- Being able to write a scientific report
  - Content:
    - Take into account the purpose and the characteristics of the reader
    - Describe the content correctly
    - Stress the results of the project
  - Formulate a critical conclusion
    - Formality of the text:
      - A clear structure (title, introduction, elaboration, conclusion)
      - Formal written language
      - Refer correctly to sources
      - Assign a number and title to all figures and tables and refer correctly to the numbers
- Formulate a clear question to the team members, the tutor and the course specialists
- Being able to make a website, poster or flyer about one particular subject
- Make a 3D model of an object using SolidEdge

- Being able to give a scientific presentation:
  - Content:
    - Take into account the purpose and the characteristics of the public
    - Describe all different aspects of the project correctly
    - Stress the results of the project
    - Formulate a critical conclusion
  - Formality of the presentation:
    - Timing
    - Readable slides
    - The use of correct language
    - Present fluently
    - No excess of special effects
    - Use clear graphs, tables and figures, make sure the axes are named
    - A clear arrangement of topics

Teamworking skills

- Divide the team efficiently into subteams
- The roles of project manager, secretary and team player during the team meetings and during the teamwork.
- Organise efficient team meetings
- The use of a portfolio

Teamworking skills are gradually introduced during the first semester. The following table summarises the different aspects of efficient team functioning.

	During the team meeting	**During the teamwork in subteams**
Team player	▪ Contributes positively and creatively to the discussions ▪ Listens respectfully to the opinions of team members	▪ Works on the subtasks as it was agreed during the team meeting. ▪ Takes the subtask seriously
Project manager	▪ Introduces the agenda-items ▪ Formulates clear conclusions and tasks ▪ Makes sure that every team member is involved in the discussion	▪ Monitors the progress of the teamwork ▪ Involves actively all team members
Portfolio	The secretary makes a report of the team meeting: ▪ Evaluation of the activities ▪ Tasks and responsibilities	▪ The portfolio bundles documents that show the results and progress of the team. ▪ Each subteam makes a clear document of the work done.

2.5 Learning environment and corresponding learning activities

2.5.1 Introduction

Because of the variety of objectives and student characteristics, different *teaching methods* are integrated within 'Problem Solving and Engineering Design'.

Each semester starts with *introductory lectures*, explaining the concepts of the course.

In the first part of the semester *instruction lectures* introduce technical skills. They are accompanied by *exercises* in small groups of about 30 students, to give each individual student the opportunity to practice. These skills will be used later on during the teamwork. To make sure that every student has mastered the necessary competencies, there is an individual test for each skill.

In the second part of the semester *teamwork* starts. *Engineering lectures* discuss more in detail the application of technical skills. They are programmed just in time and as short as possible (Hmelo-Silver, 2004; Janssen-Noordman and Van Merrienboer, 2002; Janssen-Noordman and Van Merrienboer, 2002). Preferably experts are invited to give the students a broader perspective on the engineering profession and provide detailed technical information. That way the students are challenged to look at the broader technological perspective and reflect upon the real world context.

2.5.2 Introduction and engineering lectures

2.5.2.1 Introduction of the course

Each semester begins with an introductory lecture explaining the concept of the course, the objectives, the practicalities and timing.

Because of the variety of objectives and learning activities, it is important to give the students an overview of the semester. First year students also need reassuring about the guidance while working on the team project. A lot of attention also goes to explaining the evaluation system (see paragraph 2.6 Evaluation).

Students can take again a close look at all of this at home in the manual of the course.

2.5.2.2 Introduction of the technological theme

At the beginning of the first semester the technological theme is introduced to the students by two invited experts.

These lectures should motivate the students and increase their interest for the subject. It is important to show the technological relevance of the theme and indicate its benefits for society. The speakers are asked to refer to the application of basic scientific courses within the field of their expertise.

2.5.2.3 *Guided tour in the scientific library*

In the second week of the first semester the staff of the scientific university library 'Campusbibliotheek Arenberg' organises a lecture about information skills and literature search accompanied by a guided tour in the library.

At the end of the tour the students get a literature assignment. Starting from a clear research question within the technological theme, students perform a search in the literature and write a short scientific report (two pages maximum). The assignment is accompanied by clear guidelines about writing a scientific report and some examples of concrete research questions.

This is the first exercise the students do about information and written communication skills. All students get extensive feedback on their work by the didactic team.

2.5.2.4 *Group functioning*

Learning to work in a team is an important objective of the course.

Before the teamwork starts, an invited speaker introduces group functioning. He discusses about the definition and variety of teamwork and situates it within the context of the educational concept of the Katholieke Universiteit Leuven, Guided Independent Learning, and the objectives of academic education. To stimulate critical reflection about their teamworking skills, the expectations and concerns students may have from previous experiences in group are discussed in detail. The remainder of the lecture focuses on the objectives of working in group, the effects of student characteristics on teamwork and the evaluation of teamwork.

The above general characteristics of teamwork are applied more specifically to the course 'Problem Solving and Engineering Design' by a member of the didactic team. The organisation of the teamwork and the guidance of the students are discussed in detail. Also the student marking and practicalities of the course, which were already briefly discussed in the introductory lecture, are repeated.

Because the feedback from students indicates that they do not always see the immediate use this lecture, since the academic year 2008-2009 an introductory team session replaces the lecture about group functioning. This team session starts with very brief instructions and after that the students gather within their teams in the design room for the first time. By means of the Lego® Serious Play® concept (http://www.seriousplay.com/, access date: 04/06/2010) they are asked to reflect upon teamwork and group functioning through short clear questions. Each student first makes his personal answer concrete by building it with Lego® blocks. Afterwards a group discussion follows. This method has the advantage that each individual student is involved in the reflection and discussion. Moreover the use of Lego® blocks stimulates creativity and this makes the atmosphere more open.

2.5.2.5 *Experimenting*

2.5.2.5.1 Safety

During the teamwork of the first semester the students perform an experiment. Before the experiment starts, staff from the chemical engineering department organise a lecture about safety. The importance of having a protocol and performing a risk analyses are being stressed.

After the lecture each team writes down a risk analysis of the performed experiment to practise this skill. This is a part of the team assignment and they get feedback from the didactic team.

2.5.2.5.2 Sensors and labview

After conducting the experiment of the first semester, a staff member of the mechanical engineering department explains the experimental set up and the functioning of the sensors.

Also the measurement software Labview (National Instruments) is briefly introduced. This software is used on the computer to operate the experiment and gather the data. In the first semester, the students use a readymade program on this software to process the data from the experiment. (In the second semester, the students will use the same software to model processes by means of Finite State Models.)

2.5.2.6 *Project planning*

Systematic problem solving also implies the use of a systematic way to plan a project. In the beginning of the second semester project planning is introduced. The lecture explains the importance and use of a good project planning.

More in detail the following tools are supplied:

- a *task structure*, which breaks down the assignment in subtasks,
- the *responsibility chart* that assigns a responsible team member to each subtask,
- the *team calendar* with an overview of all important dates and deadlines and
- the *Gantt chart* in which the succession of different subtasks is visible.

The dynamic nature of a project planning is stressed. Students are encouraged to evaluate their progress regularly and if necessary adjust the remainder of their planning.

2.5.2.7 *Design methodology*

Systematic engineering design is another important objective of the course. The students apply a design methodology while working on the assignment of the second semester, which consists of a closed design project. Before the teamwork starts, a lecture introduces a *simplified linear design process* (Figure 2-4).

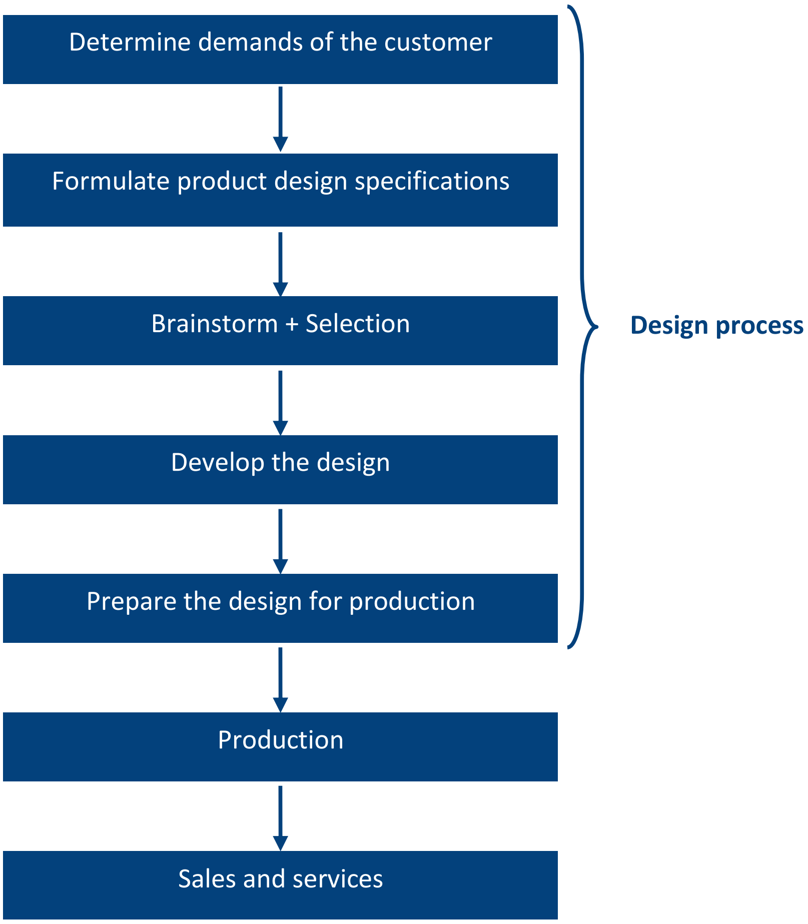

Figure 2-4. Simplified linear design process (Denayer et al., 2003).

While working on the project of the second semester, the students perform the first four steps of this design process:

1. Analyse the assignment and determine the demands of the customer by formulating all requirements for the design, including market and social requirements.
2. Formulate product design specifications by drawing up a functional decomposition. By means of a tree diagram the customer demands are broken down into very specific product specifications. These can be functional as well as economical and are as specific and quantitative as possible.
3. By means of a brainstorm different alternative design solutions are generated. After evaluating the alternatives through a brief literature search, the selection of the design concept is being performed using a value analyses. For this analysis a matrix including all valuable alternatives together with the design specifications is drawn up. If necessary there can be different weights assigned to the specifications.
4. The concept of the chosen design is formulated in detail accompanied by a manual sketch. This concept can be elaborated more in detail, entailing calculations, design sketches, technical drawings, performing an experiment, building and testing, ...

2.5.2.8 Mechanical and electronic parts

The design project of the second semester encompasses the building, testing and demonstration of their design. Because most of the students are not familiar with technical components, engineering lectures are organised to give a brief introduction.

A mechanical engineer introduces the most common mechanical parts and discusses their use. The exact parts that are discussed differ a bit according to the technological theme and the particular assignment. Topics that can be discussed are joints (welding, soldering, glue, screws, rivets, ...), springs, axes, bearings, frames, transmission (gears, chains, and belts), piping and sealants.

A staff member of the electronical engineering department explains the use of electronical components. Again the exact topics differ according to the assignment of the design project. Topics that may be discussed are the laws of Kirchhoff (for electrical potential and power), electrical components (resistance, capacitor and its polarity, diode, LED, transistor, relays, amplifier) and the use of sensors, actuators and a microcontroller in an electronic system.

2.5.3 Instruction lectures accompanied by exercises

2.5.3.1 Introduction

For particular technical competencies, which demand extensive coaching and for which it is important that all students master them, instruction lectures are organised in the beginning of the semester to supply the students with the necessary tools to apply in the teamwork. Exercises accompany the lectures, to give every individual student the opportunity to practice the skills. The exercises are organised in small groups, so every student gets individual guidance and feedback.

In the first semester for two competencies, technical drawings and efficient use of ICT tools, six instruction lectures are organised accompanied by six exercises of two hours each.

In the second semester, students already learned to master new information more independently, so there is only one instruction lecture scheduled for every competency. This lecture is accompanied by a homework assignment and two exercises of two hours each.

Because every student needs to master these skills individually, a small test is organised per competency. Students get individual marks for their performance on this test.

2.5.3.2 Technical drawings

Technical drawings are important communication tools for the engineer. The experience in the former curriculum learned that first year students need extensive coaching to learn to read and make technical drawings, by hand as well as with the computer using Computer Aided Design software.

In the first semester students get an overview of the common projection methods (orthogonal, isometric, axonometric, parallel, and central projection and perspective drawing). Furthermore they practice reading technical drawings and manual sketching techniques.

2.5.3.3 ICT tools

Efficient use of ICT tools is important for making correct calculations, writing clear reports and search for information. In the first semester students get an overview of word processing, spreadsheet, slideshow, Maple, internet and the World Wide Web. Furthermore the lectures provide tools to work collaboratively by using a computer.

Because of the diverse prior knowledge of the students concerning ICT tools, some of the lectures are organised as private study. The electronic learning environment, Toledo, provides the necessary coursework. During the exercises, teaching assistants provide more guidance if necessary.

2.5.3.4 Modelling of objects

In the second semester students use Computer Aided Design software (Solid Edge) to model designed products and make the necessary technical drawings. The students start by making a three dimensional model of two parts of the experimental setup for the demonstrations at the end of the second semester. The two parts build up in complexity. Starting from their own models, the students make the assembly complete using predefined parts and derive the correct technical drawings.

2.5.3.5 Modelling of processes

In the beginning of the second semester, the modelling of processes by using Finite State Machines is introduced. In the accompanied exercises the students use Labview (National Instruments) to model the control of a simplified elevator.

2.5.4 Teamwork

2.5.4.1 Introduction

Halfway the semester teamwork starts. Learning to work efficiently within a team is an important objective of the course. Furthermore cooperative learning has a lot of benefits when it is implemented carefully (see chapter 1).

Teams of eight students are working one afternoon a week on a project in the design room. Eight students in one team is a lot, but feasible. This was decided due to the large number of students that take the course in their first year. Each team is coached by a tutor, who facilitates the teamwork and provides the students with feedback on the content of the project, the process of problem-solving and the team functioning.

In the first semester the students work on closed engineering problems within one technological theme. The assignments indicate subtasks and problem solving methods. Gradually the teams become more responsible for planning their work within the team sessions.

The assignment of the second semester consists of a closed design project. The teams work during the whole semester on the same assignment and have more responsibility in planning their own work.

The next paragraph gives an overview of the generic aspects of the teamwork assignments. After that the organisation of the teamwork and the guidance of the students are being discussed.

2.5.4.2 Contents

2.5.4.2.1 <u>Introduction</u>

To attain the stated objectives gradually throughout the two semesters, the assignments are designed carefully. This section describes in detail the structure of the subsequent assignments and their requirements.

This framework is not dependent on the technological theme and therefore can be re-used with other actual subjects and design-products. This makes it easier to implement a whole new set of assignments within a new technological theme. The next chapter (chapter 3 *Actual implementation within two different technological themes*) describes the application of this framework within the two existing themes: ‘aerospace engineering’ and ‘energy’.

2.5.4.2.2 <u>First semester: closed assignments</u>

Introduction: orientation within the technological theme and overall assignment

The *first assignment* is to perform a brainstorm and use a mind mapping technique for analysing the central question that combines all three assignments of the first semester within the technological theme. The students draw a schematic overview of their ideas, including mainly technological aspects. They indicate possible applications of the scientific courses (calculus, mathematics, chemistry and mechanics) in the diagram.

Each team discusses their outline with the tutor. Together they define subthemes that correlate with the three team assignments of the semester. That way the students can see the broader perspective of the assignments and the connection between their regular courses and the technological theme.

The competencies that are practised by this first assignment are systematic problem solving and teamworking skills.

The *overall deliverable* of the semester consists of a website (2003-2004), poster (2004-2005 and 2005-2006) or flyer (2006-2007) that demonstrates the applicability of basic scientific theories within the technological theme. The students use a research question as main topic and discuss how it was elaborated during the team sessions. They are encouraged to indicate clearly the applied theories of the scientific and technical courses.

Students work on this overall assignment during the whole project. Especially during the last two weeks of the semester, a subteam finishes the overall deliverable of the project.

The competencies that are important for the overall assignment of the first semester are course integration and communication skills.

Assignment 1: closed mathematical modelling assignments within the technological theme

The first assignment consists of closed mathematical modelling assignments within the technological theme. The emphasis lies on the application of basic theories of the regular scientific courses and the integration of different courses to solve a problem. Students are encouraged to write down a short overview of the applied theories.

The problems are as authentic as possible. The assignments refer to real situations and use data students can look up themselves.

Students make numerical models of the problems and solve those using spreadsheets and Maple. The assignment indicates the solving strategy. That way, students are taught to use at first a very simplified model to get a first impression of the result. This model can be gradually made more accurate (which will make it harder to solve).

Competencies that are practiced in this assignment are course integration, information skills, modelling, ICT-tools, problem solving and teamworking skills.

Assignment 2: experiment

The second assignment consists of performing an experiment, which integrates different disciplines. Students already get more responsibility and work on this assignment during three team sessions. It consists of different subtasks:

- Before the experiment starts students get a lecture about safety and learn how to formulate a risk analysis. Later on, each team makes a risk analysis of the performed experiment.
- Each team makes a numerical model of the experiment, using basic theories of the scientific courses and solving it using Maple. The numerical model integrates mechanics, chemistry and calculus.
- Starting from the mechanical parts and the technical drawings, each team assembles the experimental setup. A staff member of the mechanical department gives a short lecture about the experimental setup and the sensors that are used. Also the measurement program labview (National Instruments) is briefly introduced.
- After performing the experiment, the students process the data using Labview (National Instruments) or a spreadsheet.
- Each team makes a critical evaluation and compares his numerical model with the results from performing the experiment.
- The final deliverable of this second assignment consists of a scientific report. Based upon the feedback they received on their literature assignment, students are reminded of the guidelines for writing scientific reports. Each team gets intensive feedback on their report afterwards and they are encouraged to correct them accordingly.

- Students mainly practice the following competencies while working on the second assignment: course integration, modelling and experimenting, ICT tools, systematic problem solving, communication and teamworking skills.

Assignment 3: animation

The third assignment consists of making a small animation based on central projection using projection matrices. Students work for two team sessions on this assignment and plan that work themselves. Subtasks of the assignment are:

- Before implementing the animation in the Maple software students go through a little manual to learn how to calculate in Maple with vectors and matrices and how to define procedures.
- The students define an object and calculate the central projection of the object using matrix calculations in Maple (see Figure 2-5).
- By using the mechanical equations of motion, new coordinates can be calculated for the object for a fixed amount of time steps. By calculating the central projections for these time steps, students implement an animation of the object.
- During the third assignment students practice the following competencies: course integration, ICT tools, modelling, communication and teamworking skills.

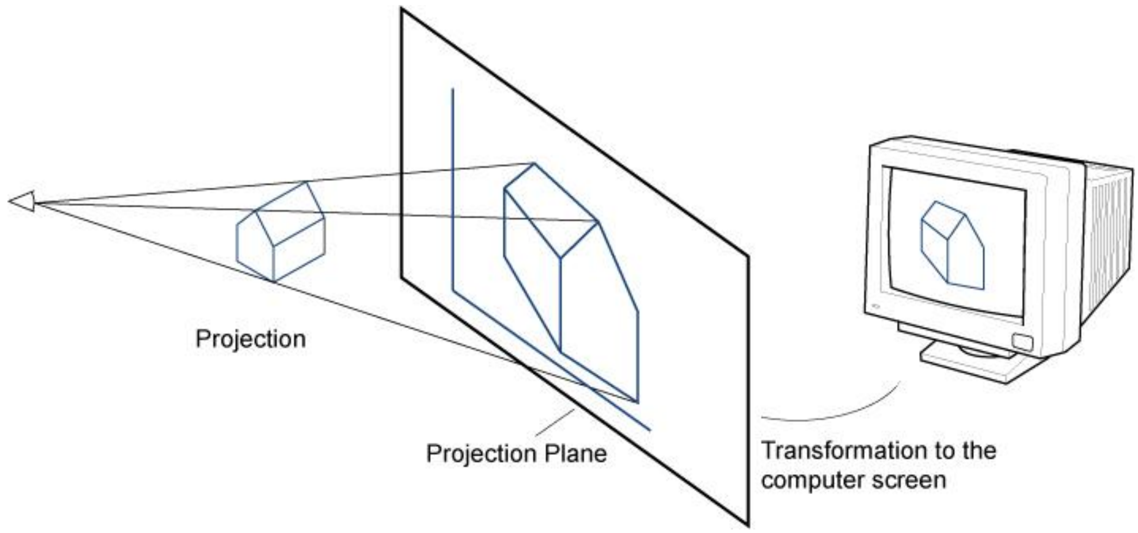

Figure 2-5. Overview of the graphical pipeline of a central projection (adjusted from (Vander Sloten et al., 2002).

2.5.4.2.3 Second semester: closed design project

Overall assignment

The assignments of the first semester were situated within a broad technological theme. The assignment of the second semester consists of a closed design project within the same technological theme, but this project focuses on one particular design product. This makes the project more tangible and practical. Each team gets a limited budget of approximately 25 Euros.

At the end of the semester the student teams give a demonstration of their designs. This demonstration is organised like a small competition and an external juror is invited to evaluate the designs. Furthermore each team hands in a written report about their project and gives an oral presentation.

The design assignment needs to fulfil the following requirements:

- The assignment entails a small competition, which requires an optimalisation process of the design parameters.
- It needs to be challenging for first year students. (Fast) moving design products are more spectacular and therefore motivate the students.
- Because of the limited budget, the practical building of the design object must be feasible with simple materials and instruments. The assignment should be hands-on.
- The task integrates different scientific courses and is situated within the technological theme. The scientific courses of the first year of the bachelor of engineering contain mechanics, physics, chemistry, thermodynamics, calculus, algebra and informatics. It is not possible to integrate all courses in the same assignment, but the goal remains to use at least five or six of them.
- Each team consists of eight students that work together on the same design and learning to communicate efficiently is an explicit objective of the course. Therefore the assignment needs to encompass multiple subtasks (for eight students to be able to work simultaneously in the design room), for which communication within the team is necessary to succeed for the course.

To meet these requirements the design assignment of the second semester contains typically the following subtasks:

- *Project planning*

  The first team session starts with a brief introduction of the assignment. After that the teams start by analysing the assignment and defining the subtasks.

  The students work on the design assignment during eight weeks (this is eight afternoons of 4 hours each in the design room). Each team makes his own project planning for the whole semester, consisting of a task structure, responsibility chart, team calendar and Gantt chart.

- *Subtask 1: design and build*

  Main goal of this assignment is to design a particular product. Students apply the simplified linear design process, which was introduced in the beginning of the semester (Figure 2-4). Additional inspiration is provided by engineering lectures about mechanical and electronical components.

Students need to make this design with a limited budget and simple tools.

The students use Solid Edge to make 3D models and technical drawings of their design.

To stimulate creativity, the success in the competition between teams is directly related to the design component of the assignment. The students build their own design, perform tests and optimise their design product.

- *Subtask 2: numerical simulation to optimise a parameter*

  The project assignment of the second semester contains a competition between the designed products at the end of the semester. Examples of such competitions are: the design water rocket needs to fly as high as possible or as far as possible. Because of the competition element the students need to optimise a particular parameter of their designed product (in the example for instance the amount of water in the water rocket). Therefore each team makes a numerical model of the demonstration, applying different scientific disciplines.

  The students first make an overview on the whiteboard or on paper and discuss this with their tutor before starting the implementation in Maple on the computers. Preferably they start by calculating a very simplified model to get a first idea of the results. The model can be made more complex later on in the semester.

  For these calculations, students can benefit from the experience of the first semester. They can re-use the general calculations they made in the first semester and apply them to the more specific design case.

  Based upon the calculations the design can be optimised.

- *Subtask 3: experiment to measure a characteristic of the design*

  The characteristics of the design product are input parameters for the numerical model. To know them as accurately as possible the students perform an experiment prepared by the didactic team. Labview is used as measurement program and the students use it to process the raw data gathered during the experiment.

- *Subtask 4: Demonstration*

  In the 8th week of the project, the students demonstrate their designed product. Each team gets two trials to demonstrate its design.

  During the demonstration the performance of the design is measured and demonstration is recorded using a video-camera.

  The demonstrations are organised like a small competition and an external juror is invited to evaluate the designs. Each team explains briefly their design concepts to the juror.

- *Subtask 5: Evaluation of the results of the actual demonstration compared to the numerical simulation*

  By using the data gathered during the demonstration, the students evaluate the result of their designs.

  By considering the video data to be subsequent central projections, the actual coordinates of the images can be calculated using matrix transformations. Students can re-use the equations from the third assignment of the first semester (animation) to analyse the video-data. The software Vision Assistant of National

Instruments, helps to calculate pixel coordinates of the images. To get a quick result, the students can use two reference points by which the software can make a first rough estimation of the actual coordinates by extrapolation.

- *Subtask 6: write a report and give an oral presentation about the project*

  At the end of the project each team hands in a written report and gives an oral presentation about their project. A template suggests the different topics to discuss:

2.5.4.3 *Materials*

2.5.4.3.1 <u>Course handouts</u>

All students have the course handouts. They contain an introduction to the course concept with a detailed time schedule and some practical arrangements, contact information, details about the evaluation process and a detailed overview of the course objectives. Furthermore the manual consists of general documents with guidelines concerning the particular objectives: the teamwork and its organisation, tips for systematic problem solving, tips for writing a scientific report, giving a scientific presentation and making a scientific poster, project planning and the simplified linear design process. That way all students keep a copy of these documents to consult later on in their curriculum.

2.5.4.3.2 <u>The electronic learning environment Toledo</u>

Most of what is in the manual is also subject of a short lecture that is programmed just in time, to give the students a structured overview. The *slides* from all the lectures are assembled on the *electronic learning environment*, where the students can consult them. The electronic learning environment is used for all communication concerning the course: between the staff and the students, but also within the student teams themselves.

2.5.4.3.3 <u>Paper instructions</u>

The *assignments* themselves contain a detailed time schedule and a lot of tips about the way to start working and solve the problem. The instructions refer to specific chapters of the manual and to chapters of the regular scientific courses.

The instructions reflect the gradual transition from closed assignments to more open projects. Gradually the student-teams become more responsible for their own projects. In the beginning of the first semester the instructions indicate clear subtasks and problem solving methods. Gradually the assignments are formulated more openly with respect to the content of the assignment as well as the team functioning. First the assignments indicate how to divide the team into subteams and when to organise a team meeting. In the second semester students make their own project planning and assign team roles themselves.

Project work per definition has a somewhat open end and lacks a specified predefined deliverable. To motivate the students, the assignments of the first semester define feasible minimum deliverables (with extras) (Bot et al., 2005; Ringwood et al., 2005).

2.5.4.3.4 The mini library

All work is done in the *design room*. This room consists of fifteen design studios where teams of eight students can work on their projects. Each studio has a meeting table, four personal computers, a white board and a bookcase. Furthermore the design room has a corner for performing experiments and building of design products and a small *library*. The library contains all textbooks of the regular courses of the first and second semester of the curriculum, together with general manuals and reference works (chemistry, mathematics, the software Maple, ...).

2.5.4.3.5 The team portfolio

The bookcase in each student design studio contains the team *portfolios*. This portfolio is a structured collection of carefully selected documents that displays the results and progress of the teamwork. The portfolio therefore is the final deliverable of the teamwork. The didactic team uses it to evaluate the team. Course integration is an important objective, so the students are encouraged to use the portfolio to show clearly how they applied basic scientific principles to solve the team assignments. The students are forced to make handwritten short abstracts about the basic principles and theories they apply to solve the problems ('thinking on paper'). This prevents them from jumping too soon to the computer implementations, which are less important (Davis, 1998).

Furthermore the students themselves use their portfolio as a logbook to monitor their progress. Because the work is divided among different subteams, the portfolio contains a lot of useful information about the content of the project. Each team has a paper portfolio in their studio, as well as a digital one on the file server. Both need to be well organised.

Every student fills out an *individual logbook* at the end of every team session. This logbook is part of the team portfolio and contains the activities of the student concerning the teamwork. Students can include reflections about their learning progress or important insights about the team project. They should refer always to the objectives of the course (by using a numbered list). Doing so, the students are more aware of their learning objectives and are encouraged to take on different kinds of tasks.

Besides the presentable portfolio, the teams' bookcases contain also *store-boxes* for rough work, unfinished documents, schedules, ...

2.5.4.4 Organisation of the teamwork

2.5.4.4.1 Team formation

Eight students work together in one team. For project work a team best consists of 4 to 6 students (TREE Teaching and Research in Engineering in Europe, 2007). Because of the large number of students that take the course in their first year, the working group of professors decided to form teams of eight students to make the organisation and the guidance manageable.

The teams are formed randomly by the didactic team to make them heterogeneous (Davis, 1993).

It has been recommended to create conditions that promote the development of a good intra-group socio-emotive quality, to install cooperative relationships between group members, to create a social environment where team members trust each other, where they feel 'they get on with each other', and where they experience a sense of community and social cohesiveness (Von Krogh et al., 2000). Buelens et al. found that also the intra-group socio-emotive quality (SEQ) within a team of learners that cooperate for a longer time greatly affects the quality of the final outcome of the project work (Buelens et al., 2005). Moreover, they observed that the level of SEQ within a team of co-learners a) is determined early on in their common history, i.e. after a few meetings and b) remained stable for a very long period (several months). As a consequence, a team that does not succeed in establishing a good SEQ at the start, imposes a burden on the remainder of its own future, both in terms of 'getting on with each other' as in terms of reaching a valuable final outcome. Because the start of the teamwork is crucial for the team functioning, the team composition is made public at the very last moment; this is at the beginning of the first team session.

During the first team meeting the students come up with a team name (Davis, 1993). This breaks the ice and supports team coherence. Next a team agreement is formulated which makes team norms more explicit (Ruiz de Elvira, 2004; Woods et al., 2000).

Each semester teams are reorganised, i.e. new teams are formed at the start of a new project. In this way all students can start over without prejudices and have the opportunity to combine different learning experiences.

2.5.4.4.2 Team roles

Three main team roles are specified for the teamwork: project manager, secretary and team player. The *project manager* is responsible for coordinating the teamwork and leading the team meetings. The *secretary* makes a report of the team meetings based on a template. He or she has also the final responsibility for the portfolio. This portfolio can be checked by the tutor at the end of each team session. Being a good *team player* is an important element in efficient group functioning. A good team player tries to perform the assigned tasks with a good result, works creatively and with a positive attitude and cooperates during the team meetings. He respects the opinion of the other team members and strives to reach a consensus within the team.

At every moment each role needs to be assigned to a team member. In the first semester students assign a new project manager and secretary each team session. That way most of the team members get the opportunity to practice the skills necessary to fulfil these roles. The manual contains detailed guidelines for the different roles. A different set of guidelines is made up for each role, with tips for the team meeting and the teamwork. In the course of the first semester, special attention is being paid to the different team roles.

In the second semester students are more responsible for their own team functioning: they assign the different roles themselves and choose whether they want to rotate these responsibilities during the semester. In the second semester each team also needs a treasurer, who is responsible for the team budget.

2.5.4.4.3 Team meetings

In the first semester, each team session starts and ends with a team meeting. If necessary, the project manager can organise an extra team meeting during the team session. In the second semester the students decide themselves when to organise a team meeting.

Generally the agenda of team meetings contains the following items: check the previous meeting report, evaluation of the activities, planning, and reflection with respect to the objectives. Students are encouraged to make critical evaluations of their actions and agree upon specific conclusions.

The project manager leads the team meetings and introduces the items on the agenda. He makes sure that every team member is involved in the discussions and mediates when there are disagreements within the team. At the end of a discussion he formulates clear conclusions. The manual of the course contains a check list of guidelines to help the project manager during the team meeting. The efficiency of a meeting however depends on the cooperation of all team members present. Students should realise this, therefore the manual contains also a list of points of interest to have a constructive meeting.

Based upon a template, the secretary writes down a report of the meeting. The report is not a chronological diary, but a structured overview of the evaluation of the activities and all decisions and points of actions that followed. The first part of the report gives a brief overview of all discussed topics. The second part states all points of action with the assigned responsible team members and a timing. This report has several objectives. The team members use it as a reminder and it supports later team meetings. Furthermore it provides a source of information for team members that were absent or member of the didactic team.

2.5.4.5 Guidance of the students

A lot of attention goes to the guiding of the student (Hansen, 2004). The variety of information sources provides a kind of blended learning.

The *manual* of the course contains an introduction to the course concept and general documents with guidelines concerning the objectives.

Most of what is in the manual is also subject of a short *lecture* that is programmed just in time, to give the students a structured overview (Hmelo-Silver, 2004; Janssen-Noordman and Van Merrienboer, 2002).

The *assignments* themselves contain a lot of tips about the way to start working and solve the problem. The instructions refer to specific chapters of the manual. However it is the experience of the didactic team that short just in time lectures have a positive effect on the project results. Because the instructions are sometimes long, students tend not to read them carefully enough. This is a problem because the amount of personal guidance is limited to three tutors for 12 to 14 teams of eight students.

For the project work, each team is assisted by a *tutor*. He facilitates the teamwork and provides the students with individual feedback on the content of the project, the process of problem-solving and the team functioning. He does not provide ready-made answers, but emphasises self-support. The tutor has several responsibilities:

- The tutor is well prepared with respect to the content of the project (Clement et al., 2004; Hansen, 2004; Weenk et al., 2004; Moust, 2001).
- The tutor explains the minimum requirements of the project and encourages the teams to get a good result (Johnson et al., 1998; Clement et al., 2004).
- The tutor encourages the students to take advantage of the cooperative learning (Clement et al., 2004; Hansen, 2004; Hmelo-Silver, 2004; Weenk et al., 2004; Dolmans, 2005; Johnson et al., 1998; Moust, 2001).
- The tutor stimulates the students' self-activation and reflection (Bary and Rees, 2006; Clement et al., 2004; Hansen, 2004; Hmelo-Silver, 2004; Millis, 2002; Woods et al., 2000; Dolmans, 2005; Moust, 2001).
- The tutor provides useful feedback with respect to the team progress as well as individual student learning goals (Clement et al., 2004; Hansen, 2004; Rosca, 2005; Dolmans, 2005; Johnson et al., 1998).
- The tutor evaluates the team and monitors individual contributions of team members based on individual logbooks, the team portfolios and daily observations.

In addition to the tutors, *course specialists* are invited as experts to explain more in detail the use of the basic principles taught in the regular scientific courses. This supports the course integration, an important objective of 'Problem Solving and Engineering Design'.

The students get gradually more involved in the guidance. During the first semester the course specialists relevant for the particular assignment are present in the design room during the whole team session. In the second semester, where the project planning is made by the team, the students can add their team number on a reservation list for a particular course specialist. That way the teams get more autonomy and responsibility for their project.

Because the tutors play a central role in the teamwork, it is important to pay attention to their training (Savery, 2006).

- New tutors first make the assignments themselves. The results are discussed within the didactic team and compared with example solutions.
- To coach the team functioning the tutors use a list of points of interest.
- A new tutor is assisted by other members of the didactic team that have more experience in guiding the teamwork.
- The three tutors discuss their guidance and share tips and observations.
- A detailed list with in between results helps the tutors with the correction of team results.
- The feedback template makes sure that all tutors give uniform feedback to the teams. The template provides a list of topics on which every team needs feedback.
- The evaluation template helps the tutors to evaluate and mark the teamwork. This template provides a way to note the progress of a team in the course of the semester.

For performing experiments the students are guided by members of the *technical staff* of the Engineering Faculty. Because the large amount of students, the schedule is strict and the experimental setup needs to be student proof. The assignment of the second semester consists of a design exercise in which students build their designs.

Because our first year students are often unfamiliar with using tools, they repeatedly need assistance from technical co-workers.

2.6 Evaluation

2.6.1 Student marking

Most of the courses in the first year bachelor follow a traditional arrangement with formal lectures and exercises in the course of the semester and one examination at the end. During 'Problem Solving and Engineering Design' students are continuously evaluated. The student evaluation is a combination of an individual result for the instruction seminars and exercises (evaluated through individual assignments) and a mark for the teamwork.

The team evaluation is a process and product evaluation of the work of a team. This mark is given by the tutor and based upon evaluation of the team portfolio and observations during the team sessions.

This team mark is fine tuned for individual contributions through feedback of the tutor (based upon the individual logbooks and observations during the team sessions) and peer assessment. This individual mark discourages free riders and rewards the very good students.

Additionally, at the end of each semester, all students take an individual test about the content of their project. That way the important objective of course integration and the application of basic scientific theories can be evaluated individually. Furthermore it encourages the students to work actively and be involved in all aspects of the assignments. This test is an open book examination where the students are asked to apply the same principles to solve similar problems.

In total about half of the mark is based on a team evaluation and half is individually determined. Teamwork tends to diminish the dispersion of the marks. Certainly when the groups are rather big (each team consists of eight students). In the first year of the bachelor the students are still very diverse regarding their capabilities. The marking is done as fairly as possible by including the individual contributions and individual learning results.

2.6.2 Peer assessment

An objective assessment of teamwork, and the individual contribution of team members, is a difficult task. To achieve effective cooperative learning it is important that all team members are individually accountable for their share in the workload. Often co-assessment is used to grade individual students on group projects (Dochy et al., 1999). Working in a team, students want to participate in the assessment to make the results more objective. They often know in detail the contribution of each member to the teamwork. To avoid problems like friendship marking, the didactic team takes part in the evaluation of individual team members (Bostock, 2000).

A procedure has been developed that fine tunes the team mark, given by the didactic team, to an individual student score through the feedback of the daily tutor of the team and student peer assessment. The students take part in the evaluation process and judge their team members relatively to the average of their team. The peer assessment is also used as a learning tool for teamworking skills, as the students do the assessment in a formative way halfway the project and get feedback on their team functioning.

Teamwork, a didactic form which is mainly student centred, is very suitable for peer assessment since students have an active part in the evaluation process. The students are responsible for making critical judgements about the work of their team members (Sluijsmans and Dierick, 2002). In addition all students perform a self-assessment. In this way they are forced to reflect upon their own skills which offers a great learning opportunity (Falchikov, 1986). The peer assessment is not only used to grade the team assignments at the end of the course, it also affects the learning process. Halfway the course, peer and self-assessment are used in a formative way. The students reflect upon their team functioning and obtain feedback from their team members. Additionally peer assessment influences group functioning: students are more motivated to work seriously and free riders get discouraged.

The peer assessment procedure

Based upon literature (Elliot and Higgins, 2005; Segers and Dochy, 2001) and previous experiences with design projects (Denayer et al., 2003), peer assessment was implemented in 'Problem Solving and Engineering Design' in a way that it permits students to make only relative judgements about the work of their team members, i.e. relative to the average of their team. The didactic team is responsible for the absolute grading of the students. The students judge their team members on three different criteria: 'relevance of the contribution', 'amount of work' and 'quality as a team player'. For each criterion there are three possible scores: 'average', 'better than the average of the team', 'worse than the average of the team'.

Because of the large number of students enrolled in the course, an electronic peer assessment form was developed, that includes self-assessment. To make sure that each student evaluates his seven team members relatively to the average of his team, he can only grade a limited amount of four students as 'better than the average' for each criterion. A text space in the electronic form offers the students the opportunity to motivate their judgements, which is highly appreciated. In addition these explanations allow the didactic team to have a better understanding of the team functioning.

Halfway the course the students fill out the electronic form for the first time, in a formative way. This gives them the opportunity to get familiar with the peer assessment and to practice the necessary assessment skills. All teams get extensive explanation about the goals and criteria of this evaluation. They are already used to discussing the functioning of their team through several previous meetings with their tutor. Based upon the judgement of their team members, each student receives individual electronic feedback concerning the three distinct criteria (Van Camp, 2003). All results are confidential, as well as the scores entered in the electronic forms. At the end of the course a summative peer assessment follows.

Processing the peer assessment data

An algorithm was developed in Matlab® to calculate individual marks from the peer assessment data in order to adjust the team mark with maximum 20 per cent (system with bonus-points). The self-assessment is not taken into account.

The algorithm calculates this individual marks under the following conditions:

- Because the students can only judge relatively, the algorithm makes the average of all individual marks zero.
- To prevent students from influencing their own individual mark, the scores given by a student to his team members does not affect his own individual mark.
- When calculating the individual marks, the outer limits are fixed in a way that a student who gets the score 'better than the average' from all of his team members, receives the maximum possible individual mark (and vice versa).

The algorithm also generates a feedback file. Each student receives feedback on the three peer assessment criteria (relevance of the contribution, amount of work and quality as a team player). Based upon the comparison of the calculated individual mark for each criterion with a predefined limit, the students get one of three types of feedback: 'you can still improve', 'your team thinks you are doing all right' or 'your team thinks you are doing excellent'.

2.7 Summary

The implementation of the course 'Problem Solving and Engineering Design' in the first year of the bachelor of engineering fits within the context of project based learning. Internationally a variety of instructional formats are being developed and implemented under the banner of PBL (problem and project based learning). Kolmos et al. described common learning principles (Kolmos et al., 2009). In the P&O course learning is mostly organised around problems and projects with defined end-products and deadlines to motivate the students. The project work is interdisciplinary and shows the relationship between theory and practice. Furthermore competencies are being trained and students learn through dialogue and communication. A particular PBL implementation can however never be copied to other universities (Kolmos et al., 2009). This chapter described the implementation opted for in the Engineering Faculty of the K.U.Leuven. Main specific didactic principles for this instructional format are the central objective of course integration, the situation of all projects of the first year within one technological theme and the gradual building up of engineering competencies.

The course concepts fit within the socio-constructivist approach of teaching and learning. Furthermore the principles of 'Guided Independent Learning', the educational concept of the K.U.Leuven, were applied during the implementation. By taken into account the conditions for successful teamwork, the implementation makes sure that students benefit from the cooperative learning situation.

- The project work occurs in authentic and challenging technological contexts (Millis, 2002; Ringwood et al., 2005; Jonassen, 1991). While working on the project, students integrate knowledge from different basic scientific courses and work towards concrete end-products (Horváth et al., 2004; Thomas, 2000). This demonstrates the applicability and coherence of the regular courses and emphasises project management.

- The educational staff facilitates the problem-solving, but does not act as expert (Johnson and Johnson, 1989; Thomas, 2000).
- Students are gradually confronted with ‘engineering’ competencies: short just in time lecture introduce technical skills, working on the assignments students practice the competencies and they get extensive feedback from the didactic team. During the teamwork students gradually learn how to reflect on and evaluate their teamwork regularly (Johnson and Johnson, 1989; Tinzmann et al., 1990).
- The student teams are formed carefully (Johnson and Johnson, 1989) and in the beginning of the teamwork effort has been made to create a social environment where team members feel ‘they get on with each other’ (Buelens et al., 2005; Von Krogh et al., 2000). Explicit attention goes to social skills and emphasis is on face to face problem-solving (Johnson and Johnson, 1989). Roles and tasks are being assigned to individual group members (Springer et al., 1999).
- The assignments and evaluation system make sure there is a positive interdependence between team members and that each student is individually accountable for his or her part of the teamwork (Johnson et al., 1990).

Within this generic framework different sets of assignments can be developed within attractive technological themes. Chapter 3 describes two sets of actual assignments within two different technological themes (‘aerospace engineering’ and ‘energy’) that have been implemented in the academic years 2003-2004 until 2006-2007.

Because of the large number of students enrolled in each course (about 400), a rigid time schedule and a set of detailed rules for the project work are necessary. Mostly developing student-proof experiments takes a lot of time. A good communication within the didactic team and with the staff of the Engineering Faculty is essential in order to discuss the course integration and to agree on the evaluation process.

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3 Actual implementation within two different technological themes

Within the generic framework described in chapter 2 (Implementation) two sets of assignments are defined and implemented around two different technological themes that are both challenging and related to the imagination of young engineering students. In the academic years 2003-2004 until 2005-2006 the project work was related to 'aerospace engineering', which is described in section 3.2. Section 3.3 describes a second set of assignments related to 'energy'. The same building blocks are used for both sets of assignments; therefore part of the instructions could be re-used. The generic framework described in the previous chapter makes sure that the students are gradually confronted with the learning objectives of course integration and technical and social skills.

3.1 Introduction

Chapter 2 described the student learning objectives and the generic aspects of the instructional format of the course 'Problem Solving and Engineering Design', designed to help the students attain these learning goals. That way a generic framework was built in which the actual assignments for the teamwork can be formulated within a particular and attractive technological theme.

Within the academic years 2003-2004, 2004-2005 and 2005-2006, the course was implemented around the technological theme aerospace engineering. This is an exciting highly technological theme that was in the media in Belgium around that time because of the flight of the Belgian astronaut Frank De Winne. Section 3.2 will describe the assignments that were implemented within this theme.

In the academic year 2006-2007 a second set of assignments was drawn up within another technological theme 'energy'. Sustainability and careful energy consumption is a topic that is really hot at the moment and that inspires a lot of young students. Section 3.3 describes the assignments within this theme.

3.2 Aerospace engineering

3.2.1 *Introduction to the technological theme*

The technological theme 'aerospace engineering' is introduced by means of two invited speakers in two engineering lectures. The purpose of this introduction is to introduce some technological aspects of the chosen theme and to make the connection with the regular courses of the semester. In addition the lectures should make the students enthusiastic about 'aerospace engineering', design and interdisciplinary project work.

Belgian astronaut ir. F. De Winne was invited to give the first introductory lecture. Because of his engineering background - he obtained his masters degree in telecommunications and civil engineering from the Royal Military Academy in Brussels in 1984 - he was the ideal person to indicate the importance of engineering for aerospace. Furthermore he is known to a broad public because of his part in the Odissea mission in 2002, a support flight to the International Space Station (ISS). This mission made him the second Belgian in space, after which he continued to being part of the European Astronaut Corps of the European Space Agency (ESA) (European Space Agency, 2010).

In his lecture, astronaut De Winne discussed his space flight with the Russian Soyuz TMA-1 in 2002 and about 'The challenge of developing a crew transportation system'. He integrated his personal experience of the Soyuz solutions and emphasises the interdisciplinarity of the design and all systems involved: propulsion, guidance, power, abort, life support, command and control, thermal control, motion control, communication and descent control. Driving parameters in aerospace design are mass, environmental characteristics (vacuum and temperature) and the limited resources. He concluded his lecture by stressing that designing for space is 'part of the exciting world of engineering'.

In a second lecture, Prof. D. Vandepitte gave a more theoretical talk about the mechanics involved. Prof. Vandepitte is responsible for the option aviation and aerospace technology within the master program of mechanical engineering. He discussed in this lecture the basic principles of trajectory mechanics: the universal gravitational constant; circular, elliptical, hyperbolic and parabolic orbits; planets of the solar system. Finally he introduced the design of aerospace missions, the attainability of a particular orbit, chemical and electrical propulsion systems and the construction of launchers.

At the end of his presentation prof. Vandepitte gave the students a literature assignment. The students were asked to describe an aerospace mission. They needed to select a mission, search for relevant data in the literature and on the internet and write a short report including the goal of the mission, the apparatus on board, the nature of the orbit and the trajectory necessary to reach this orbit. For helping the first year students the instructions include a list of possible missions to start from. Later on in the semester the students will use this self-searched information during a team assignment.

3.2.2 Closed assignments of the first semester: 'launching of a rocket to put a satellite in an orbit around the earth'

3.2.2.1 First team session: orientation and overall assignment

3.2.2.1.1 Orientation within the technological theme

The first assignment is to use a mind mapping technique for analysing the problem 'launching of a rocket to put a communication satellite in an orbit around the earth'. The students are asked to include as many technological aspects of the scenario of the launching as possible. This gives the student teams an orientation within the technological theme. Students can find inspiration for this schematic overview in the slides of the introductory lectures. Furthermore all students already handed in a literature assignment about a particular space mission.

Based on this prior knowledge, the following topics are expected to pop up in the students' diagrams: trajectory mechanics (the launching and the orbit), the design of the rocket, information and communication technology and maybe also the onboard life support systems. The latter is not really relevant because the assignment is about an unmanned mission.

Next the students are asked to include in the diagram the regular courses of the first semester (calculus, algebra, chemistry and mechanics). Together with the tutor the students define three subthemes for which they are already able to study further in the semester, based upon the regular scientific courses:

1. Trajectories: mechanics and calculus
2. Propulsion: chemistry, mechanics and calculus
3. Orbits – Animation video: mechanics and algebra

The remaining assignments of the semester are thus linked with their own diagram. The students see more clearly the coherence between the different assignments and are from the beginning aware of the application of the other courses, which is an explicit objective of the project work.

3.2.2.1.2 Overall deliverable of the first semester

The overall deliverable of the first semester is a website (2003-2004) or poster (2004-2005 and 2005-2006) that demonstrates how the student teams solved the assignments and how they used the basic courses of the first semester to achieve this. The idea is to use this website or poster for high school students to show what a first year engineering student already understands of the complex technological area 'aerospace engineering' based upon the courses of the first semester.

The websites built in 2003-2004 were representative for the team portfolios.

When making a poster, students need to be encouraged to present information that is as concrete as possible, instead of describing a general overview of the semester. Therefore each team chooses one particular topic for the poster and discusses a draft with the tutor.

3.2.2.2 *Assignment 1: trajectories*

3.2.2.2.1 Orbits of planets and satellites

Based on the data they gathered for the literature assignment, the students make a numerical model of the orbit of a particular satellite or planet in function of the time and plot it in a little animation. The teams are encouraged to formulate on paper or on the whiteboard the equations of motion using polar coordinates based upon either the second law of Newton or by using the conservation laws of energy and momentum. That way students can define two sets of differential equations of the first order for the movement of a satellite around an attracting celestial body. Together with the initial values, these can be solved numerically using the Maple software. By using the solved equations of motion for the satellite, the students make a small animation. That way the orbit is visualised clearly and the changes in the velocity of the satellite are visible.

This assignment shows the integration of mechanics and calculus in an authentic situation. A team of eight students is working for approximately 2 hours on this assignment. Because every student gathered individually data from a particular satellite for the literature assignment, each team can visualise different satellite orbits. In doing so the students compare circular, elliptic, hyperbolic and parabolic orbits.

As an extra assignment students can calculate the escape velocity for the planets in our solar system. For a rocket to be able to 'escape' from a planet, the velocity of the rocket needs to be large enough not to be pulled back toward the planet. Students can calculate the escape velocity for different planets by using the law of conservation of mechanical energy. (The air resistance and the gravitational attraction of other celestial bodies are being neglected.)

From the mechanics course students apply Newton's second law of motion, velocity and acceleration, the general expression of the gravitational force and the conservation laws of energy and angular momentum. The students practice formulating a general equation of motion (the position of an object in function of the time). Moreover, the assignment shows the possibility of using different methods to solve one and the same problem.

From the calculus course the students use the formulation of the equation of an ellipse in polar coordinates. Differential equations are part of the remainder of this course.

The use of the mathematical software Maple is part of the instruction seminars and the calculus course. Both use the same student manual for introducing the software.

3.2.2.2.2 Flight path of a vertically launched rocket

The second part of the first subtheme (trajectories) consists of the flight path of the Maxus rocket, which is used by ESA for microgravity research (European Space Agency, 2003).

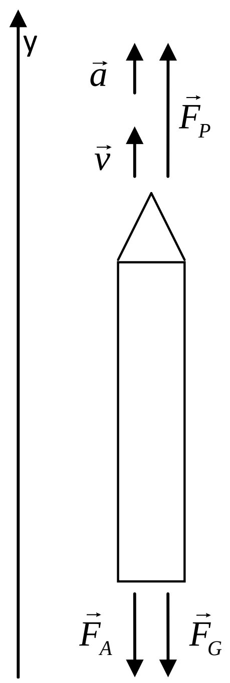
The rocket is launched approximately vertically. The students have to make a numerical model of the height of the rocket in function of the time. This assignment focuses on the integration of mechanics and calculus in a realistic problem. Relevant questions concerning the rocket are its maximum height and the duration of the flight.

Because the students use the data from the Maxus rocket, they can validate their solution by comparing measured values from a previous flight of Maxus 5. This ensures the authenticity of the assignment.

For making a numerical model, the students need to make assumptions. To get a first impression the first model is very rough and simplified. Gradually the model gets more complicated, and thereby harder to solve. The numerical model of the height in function of the time of this vertical launch is being refined in subsequent steps. Because of the launch is vertical, this is a one-dimensional problem. Students write down the numerical model starting from Newton's second law of motion, in which gradually more forces are being taken into account:

- at first only a constant gravitational force is taken into account;
- in the second model the propulsive force , generated by the linear exhaust of mass over time, is added.;
- the third model incorporates that the gravitational force diminishes with the height above the earth surface.

The students are encouraged to discuss the problem first within the whole team and make a sketch of the rocket including all forces (Figure 3-1). By gradually making the differential equation more complicated, it becomes harder to solve. A team of eight students is working for approximately 4 hours on this assignment. Different subteams start working on the subsequent models simultaneously. Therefore it is useful that students working on a more simplified model communicate their results immediately to the rest of the team.



Newton's second law of motion: $\sum_i \vec{F}_i = m \cdot \vec{a}$, with

$\vec{a}$ = acceleration of the rocket

m = mass of the rocket

$\vec{F}_G$ = gravitational force, ——,

= universal gravitation constant,
and = masses of the rocket and the earth
r = distance between the centres of gravity of the earth and the rocket

$\vec{F}_P$ = propulsive force, —,

= velocity of the exhausted mass m in time t

$\vec{F}_A$ = air resistance, –

= drag coefficient of the rocket in air
= cross section of the rocket
= density of the air in function of y, the height above the earth surface
= velocity of the rocket

Figure 3-1. Sketch of the vertical launch of a water rocket with the forces, velocity and acceleration represented by vectors.

As an extra assignment the students can also calculate the flight of Space Ship One, the world's first privately built spacecraft (Scaled Composites, 2010). Students may approximate the flight of Space Ship One again as a vertical launch. For this numerical model the air resistance is taken into account as well as the diminishing gravitational force and the propulsive force.

The students apply the following knowledge they learned during the mechanics courses: Newton's second law of motion, the definition of the propulsive force by the exhaust of mass and the air resistance. Students practice writing down a numerical model for the position in function of the time. Solving the differential equations using the Maple software fits within the calculus course.

Furthermore communication within the team is necessary and students practice their information skills because the data from real satellite missions are used in the assignment.

3.2.2.3 Assignment 2: combustion and propulsion experiment

The second subtheme focuses on the generation of propulsive forces in aerospace by the exhaust of mass. This assignment combines elements from chemistry and thermodynamics with elements from mechanics (conservation of momentum). An experiment to measure the propulsive force generated by the exhaust of water and caused by a chemical reaction was integrated into this assignment (Figure 3-2).

This second subtheme consists of three main subtasks.

1. The students conduct the experiment. This takes about two hours. This subtask is complemented by two engineering lectures: one about safety and one about the experimental setup. Each lecture takes between 30 minutes to one hour.
2. Each team makes a numerical model of the experiment to calculate the generation of propulsive force. Students have about 6 hours to make the numerical model.
3. At the end the students formulate a conclusion by comparing the model with the actual experimental results and write down a scientific report about the assignment. This takes about two hours.

In total the students work during three subsequent team sessions on this second assignment. The overall assignment indicates the time planning.

3.2.2.3.1 Experimental setup

The experimental setup represents a combustion engine that can be used for the propulsion of a rocket. This setup consists of a closed vessel which is filled partially with water and a gas mixture of butane and air on top (Figure 3-2). The gas mixture is brought to combustion using a spark plug. At the bottom there is a valve, which opens when the pressure is built up. The exhaust of the water gives the vessel a propulsive force upwards. The vessel is held into place between the frame and springs. The total force generated is measured by an accelerometer on top. During the experiment also the temperature in the top of the vessel and the pressure in the vessel are monitored.

To perform the experiment, the students follow an experimental protocol. A member of the technical staff assists the teams. Starting with the technical drawings of the experimental setup and a box containing all mechanical parts, each team assembles his own experiment. In doing so, the students apply what they have learned in the instruction seminars about technical drawings.

After assembling the vessel into the construction, the vessel is filled with 0.6 litre gas mixture of air and butane. This gas mixture is composed by 20 ml butane with 600 ml air to ensure an excess of butane gas. The remaining volume of the vessel is filled with water. The gas mixture is ignited by a spark and the combustion process is supposed to react instantly.

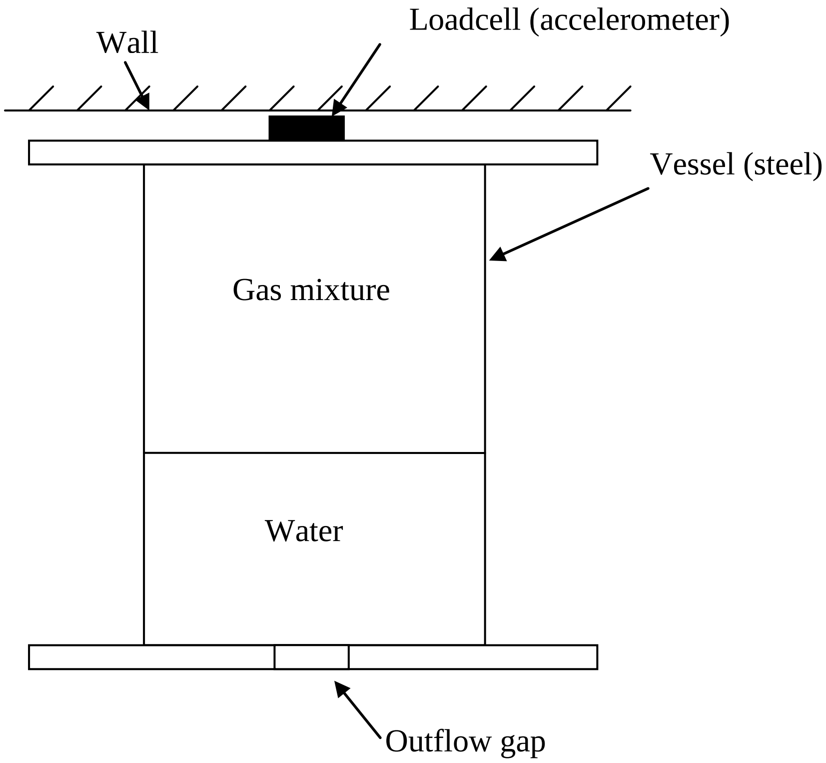


Figure 3-2. Sketch of the experimental setup consisting of a closed vessel which is filled partially with water and a gas mixture of butane and air on top.

Engineering lectures

This experiment is accompanied by two engineering lectures.

At the beginning of the assignment the students attend an engineering lecture about safety given by the staff of the chemical engineering department. Prof. J. Mewis and prof. J. Vermant introduce the concepts of safety, danger, risk, safety measures, risk analysis and personal protection. At the end of the lecture the students get an assignment concerning the experiment they perform during the teamwork. Each team writes down a risk analysis for their experiment. This risk analysis consists of a list of possible risks concerning the experiment and proposals of measures for each stated risk to diminish the risk and the damage.

After performing the experiment, all students follow a second engineering seminar about the technical aspects. This lecture discusses the measurement program Labview and explains the working of the sensors used in the experiment (a thermocouple and an accelerometer with a piezoelectric crystal).

Time schedule

For performing the experiment, each team gets a time slot within the three weeks of the assignment. Spreading the actual experiment in time is not ideal, but necessary because of the amount of teams working simultaneously. The first experiments can be scheduled the earliest in the second part of the first team session, because all students first need to read the assignment and think about the subsequent processes that occur. The latest experiments are planned in the first part of the last team session, because in the end all teams need two hours minimum to draw a conclusion and finish their report.

Figure 3-3 gives an overview of the time planning for this assignment. Four teams can work in parallel on the experiment, because there are four experimental setups. In a time slot of two hours about four teams can conduct the experiment. In the four designated time slots, a maximum of 16 teams can perform the experiment.

<table>
<tr><th></th><th colspan="4">Team session</th></tr>
<tr><td></td><td>13u50</td><td></td><td></td><td>18u</td></tr>
<tr><td>Semesterweek 9</td><td>Lecture about safety</td><td>Read assignment and make rough schedule</td><td colspan="2">Experiment or numerical model</td></tr>
<tr><td>Semesterweek 10</td><td colspan="2">Experiment or numerical model</td><td colspan="2">Experiment or numerical model (Conclusion and report)</td></tr>
<tr><td>Semesterweek 11</td><td colspan="2">Experiment or numerical model Conclusion and report</td><td>Lecture about experimental setup</td><td>Conclusion and report</td></tr>
</table>

Figure 3-3. Time planning of the second team assignment.

3.2.2.3.2 <u>Numerical model</u>

The students calculate the propulsive force generated during the experiment.

To start each team writes down a rough schedule of the subsequent processes that occur to generate the propulsive force. The subsequent steps in this schedule are:

- combustion of the gas mixture;
- release of heat by the combustion process;
- temperature and pressure rises within the vessel;
- exhaust of water after opening the outflow gap;
- generation of the propulsive force.

Next, four different subteams of two students complete the schedule by adding formulas, general constants, known and unknown variables to each step in the process. This is guided by a form for completion for each process.

Figure 3-4 gives an overview of the subsequent steps to calculate the propulsive force generated by the exhaust of the water. The combustion process with the generation of heat is supposed to act instantaneously and finish completely. The students use their knowledge of chemical reactions and stoichiometry, combustion processes, reaction enthalpy, states of aggregation, temperature and pressure of a system, the ideal gas law and isentropic expansion to calculate the energy release through the combustion process and the starting pressure in the vessel just after this combustion process. To calculate the subsequent exhaust of water, an appendix added to the instructions explains the Bernoulli law. This is not part of the regular coursework in the first semester, so the students have to practice their information skills. If necessary the tutors can explain the application of Bernoulli's law in more detail. The calculation of the exhaust of water is drawn up using incremental time steps. The generated propulsive force is then computed using the Newton postulates and the conservation law of momentum from the mechanics course. This gives rise to a differential equation, which can be solved using the maple software. That way calculus is integrated.

3.2.2.3.3 Conclusion and written report

To make sure that students get used to the significance of formulating conclusions after performing an experiment, students are forced to compare their numerical model with the experimental results.

To visualise the results, the student teams use a pre-written program in LabVIEW, a graphical programming environment for measuring, controlling and testing from National Instruments (http://www.ni.com/labview/, access date: 24/02/2010). For discrete time steps the students compare the pressure, the force and the temperature measured during the experiment with their calculations. The experimental results are measured in Volts, and the students apply the amplification factors of the sensors using the data sheets. This comparison shows that the sensors used do not react fast enough, but the overall trends are clearly visible.

The final delivery at the end of the assignment consists of a short scientific report of their work, which may fill up to a maximum of four pages. The students are stimulated to include all applied theories carefully. That way the report can be used as a useful tool during the content-test at the end of the semester. Besides the content, also the writing style is important. The manual of the teamwork contains tips for writing technical reports. Moreover students can utilize the feedback of their individual literature assignments. At the end of the semester the corrected texts are returned to the students accompanied by extensive feedback on the content as well as on the writing style. The students are encouraged to make a corrected report, to ensure that the feedback is retained longer.

Method	Formulas	General constants	Known variables	Unknown variables (to calculate)
Combustion process	Chemical equation of the combustion reaction	Stoichiometric proportions	N_i (mols of the reacting agents)	n_i (mols of the products)
Heat production	Reaction enthalpy: $\Delta H = \sum_i n_i \cdot H_{fi\_p} - \sum_i N_i \cdot H_{fi\_r}$ Heat capacity of the gas mixture after combustion: $C_{pgas} = \sum_i n_i \cdot C_{i\_p}$	H_{fi} (Enthalpies of formation of reactants and products) C_{i_p} (gas capacities of products)	N_i (mols of reactants) n_i (mols of products)	ΔH (reaction enthalpy) C_{pgas} (heat capacity of the gas mixture)
Temperature and pressure raise	Temperature raise through combustion: $\Delta T = \dfrac{\Delta H}{C_{pgas}}$ Ideal gas law: $p \cdot V = n \cdot R \cdot T$	R (universal gas constant), V_{gas} (volume of the gas mixture after combustion)	ΔH (reaction enthalpy) C_{pgas} (heat capacity of the gas mixture)	ΔT (Temperature raise through combustion) T (temperature -just after combustion) p (pressure -just after combustion)
Exhaust of water	Bernoulli law: $p + \dfrac{\rho \cdot v^2}{2} + \delta \cdot g \cdot h = Cte$ Conservation of mass: $\dfrac{dm}{dt} = v_s \cdot A_{outflow} \cdot \rho$	Geometry of the vessel (h, height; $A_{outflow}$,area of the outflow gap) ρ (density of the water) g (gravitational constant)	p (pressure)	v_s (exhaust velocity of the water) $\frac{dm}{dt}$ (mass flow of the exhausted water)
Propulsion force	Propulsive force: $F_P = \dfrac{dm}{dt} \cdot v_s$		v_s (exhaust velocity of the water) $\frac{dm}{dt}$ (mass flow of the exhausted water)	Propulsive force F_P

Time step dt

Figure 3-4. Schematic overview of the numerical model of the combustion and propulsion experiment: subsequent steps to calculate the propulsive force generated by the exhaust of water.

3.2.2.4 Assignment 3: animation of a rocket flight

In the fourth and final assignment of the first semester the student teams make an animation video of a rocket launch using the Maple software. Before implementing the animation, the students go through a short manual to learn how to calculate with vectors and matrices in Maple and how to define procedures.

The students define a rocket by using homogeneous coordinates and calculate the central projection of the object using matrix calculations. Figure 3-5 shows schematically the central projection of an object onto a plane of projection and the subsequent transformation to a computer screen.

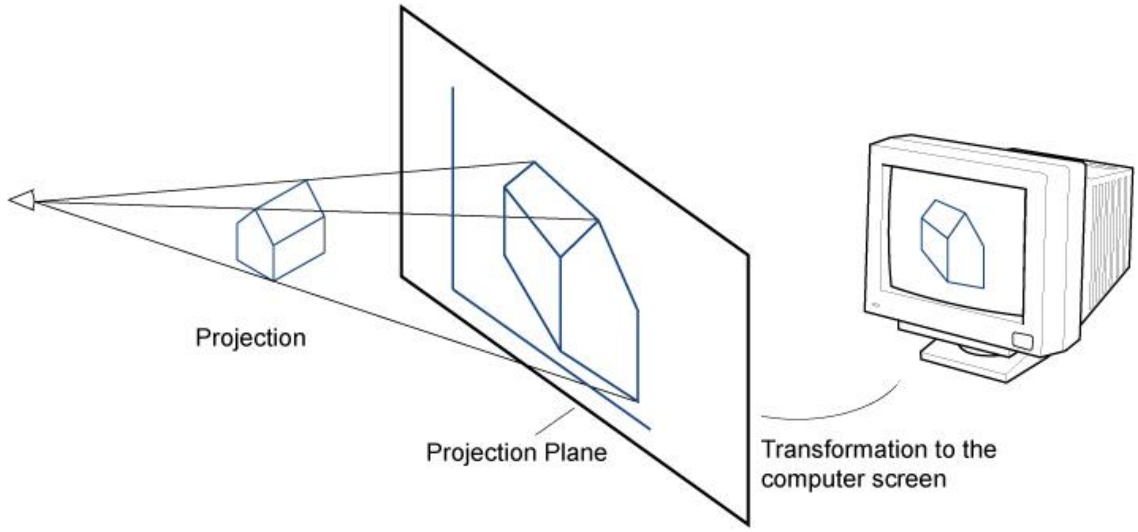


Figure 3-5. Overview of the graphical pipeline of a central projection (adjusted from (Vander Sloten et al., 2002).

By using the mechanical equations of motion, new coordinates can be calculated for the rocket during its launch at several moments in time. Students can re-use the numerical models of the first team assignment for a vertical launch. By calculating the central projections for these time steps, students implement an animation of the object.

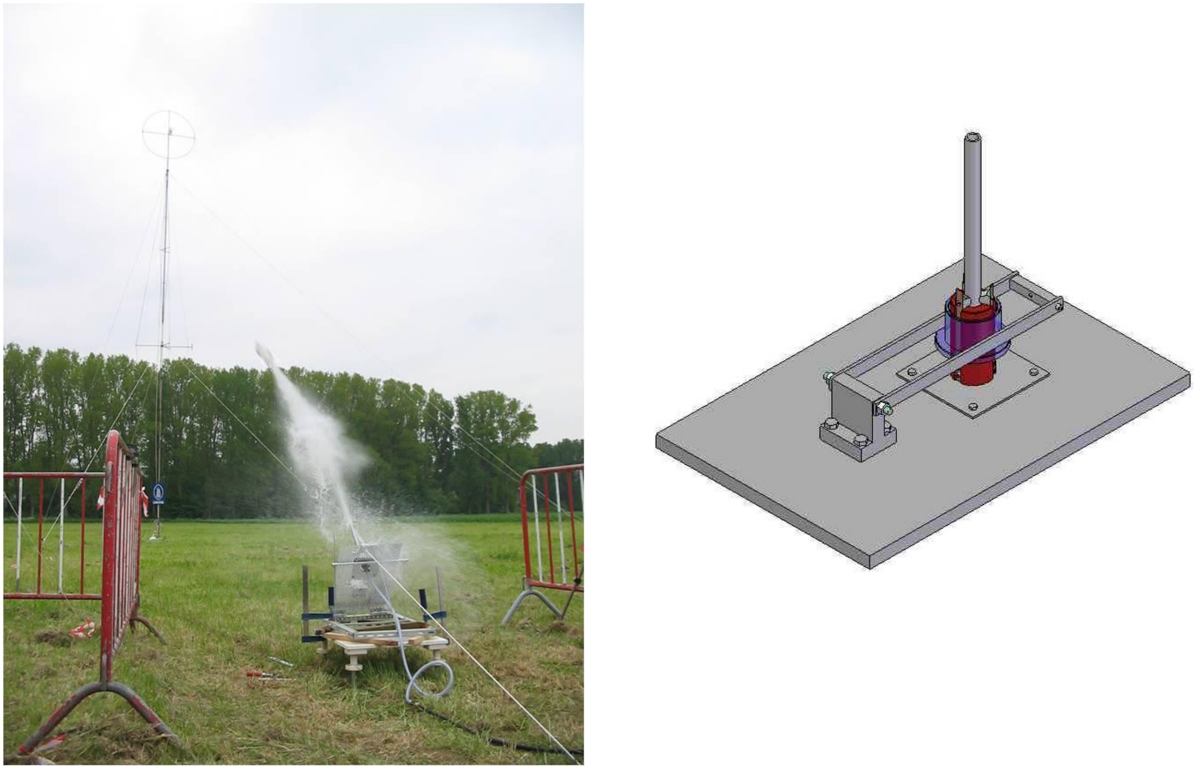
Students work for two team sessions on this assignment and plan that work independently. Working on this animation, students integrate algebra and mechanics; they use the Maple software and practice their communication and teamworking skills.

3.2.3 Closed design project of the second semester: 'design, build and launch a water rocket to reach a target'

3.2.3.1 Overall assignment

The teamwork in the second semester consists of one main project: design and build a water rocket and launch it from a platform to a target in such a way that afterwards the rocket lands as far as possible from the launching location. The target consists of a ring with a diameter of 2 meters and is situated 15,5 meters above the launching location at a distance of approximately 25 meters (Figure 3-6 a).

The water rocket is made from a PET-bottle (in particular a coca cola bottle of 1,5 litres, because they are common and fit on the launching mechanism). The bottle is partially filled with water and placed upside down over the tube of the launching platform (Figure 3-6 b). The neck of the bottle is clamped and thereby sealed air- and water-tight. The air that is left in the bottle is pressurized through the tube until an overpressure of 5 bars is reached. The rocket can be launched by pulling down the handle by which the clips are loosened and the rocket is able to move over the launching tube.



(a) (b)

Figure 3-6. (a) The target is situated 15,5 m above the launching location at a distance of approximately 25 m of the launching platform. (b) Three-dimensional Solid Edge model of the launching platform.

During the demonstration sessions, each team gets two trials to launch the rocket. All launches are either up or down wind. The launching platform is provided by the didactic team (Figure 3-6 b), except for a mechanism to give the platform an inclination with the perpendicular.

New student teams are formed in the beginning of this project. The project work is scheduled within 9 sessions of 4 hours.

Overview of the second semester

After a short introductory lecture that explains the assignment, the students first spend one afternoon analysing the overall instructions and defining their project planning for the rest of the semester. The project activities encompass designing and building the water rocket and the inclination mechanism. To optimise the launching parameters (angle and amount of water in the rocket) the students make a numerical model of the trajectory of the rocket. To complete this numerical simulation, an experiment to measure the drag characteristics of the team's water rocket using Doppler theory has to be incorporated into their project. Particular attention is paid to critical comparison between experimental data and simulation results. Demonstrations of the water rocket launching events are scheduled in week 8 of the project; oral presentations of the teamwork are scheduled in week 9 in three parallel sessions.

Each team defines his own project planning, starting from defining the task structure, making up a team calendar and assigning responsibilities. All this is represented by a Gantt chart. The students define the different subtasks themselves. The following subtasks are essential parts of their task structure:

1. design and build the water rocket and inclination mechanism
2. numerical simulation of the trajectory to optimise the launching parameters for landing as far as possible from the launching location
3. experiment to measure the drag characteristics of the water rocket (necessary to complete the numerical simulation)
4. demonstration of the water rocket
5. evaluation of the results: comparison of the actual flight data with the numerical simulation
6. written report and oral presentation

Figure 3-7 shows an example of a task structure and Gantt chart composed by a student team.

It is important for the students to realise that such a project planning is not something fixed, but that it is a dynamic instrument for their teamwork and that it can and will be necessary to adjust their planning while working on the project. At the end of the first team session each team discusses its planning with the tutor. Table 3-1 gives a general overview of the semester with indication of the deadlines. The remainder of this section will discuss the different subtasks in more detail.

Table 3-1. The project of the second semester is spread over 9 weeks. The table gives an overview of the students' activities and deadlines.

Session (4hours)	**Planned activities**	**Milestones**
1	– Introductory lecture to clarify the assignment – Project planning	– Discuss project planning with tutor
2	– Teamwork – Short lecture about written and oral communication (tips)	
3	– Experiment for measuring the drag characteristics of the rocket (– part of the teams)	
4	– Experiment for measuring the drag characteristics of the rocket (– other part of the teams)	– Premature report: state of affairs
5	– Teamwork	– Formative peer assessment
6	– Feedback from tutor on premature report – Teamwork	
7	– Demonstration days: launching of the water rocket (two trials for each team)	– Rocket and inclination mechanism – Optimisation of the launching parameters (amount of water and inclination angle)
8	– Evaluation of the actual flight by comparison with the numerical calculations	– Summative peer assessment
9	– Oral presentations – Written test	– Final report – Slides for the presentation

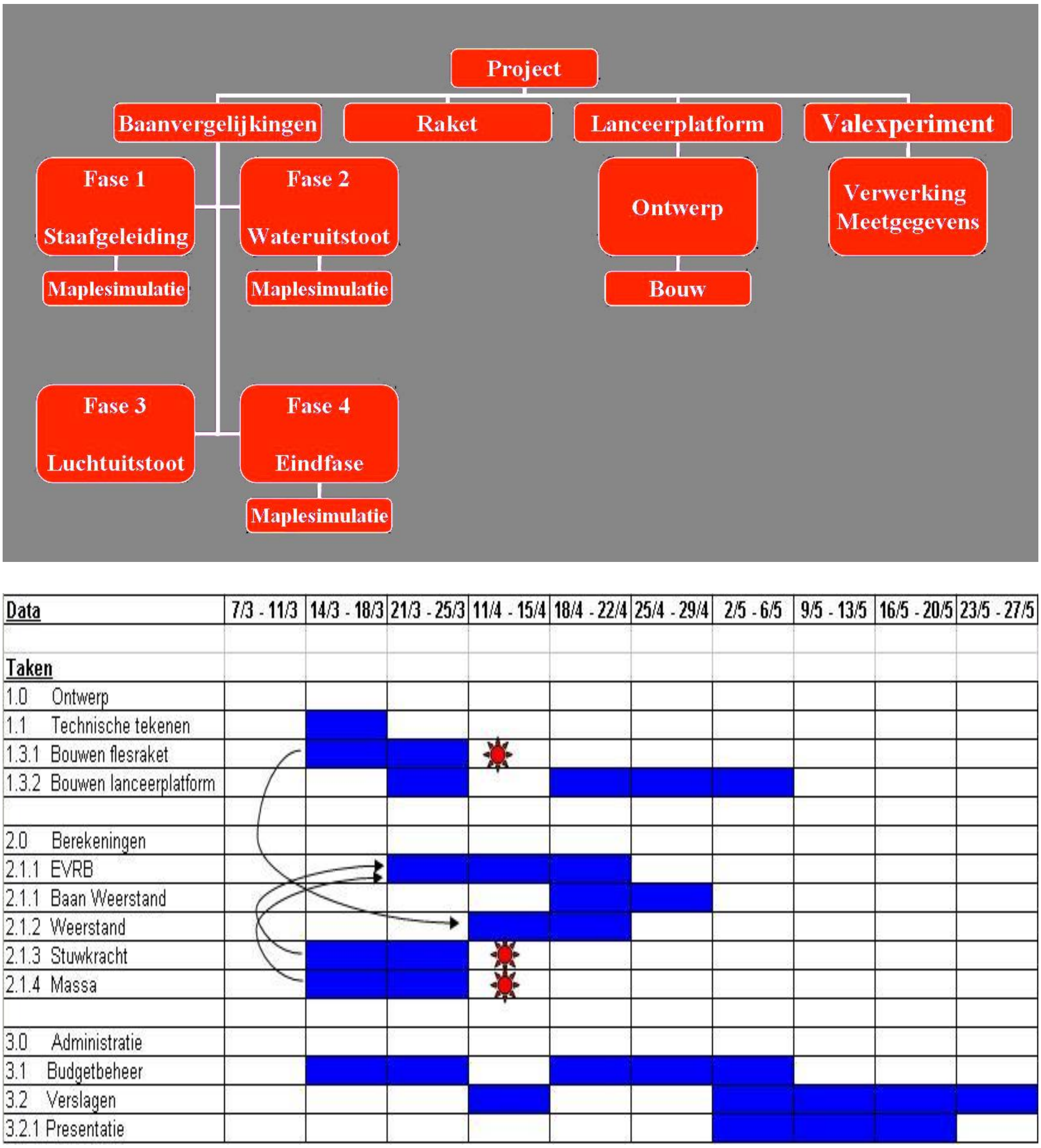


Figure 3-7. The figure shows an example of a task structure and Gantt chart composed by a student team (in Dutch).

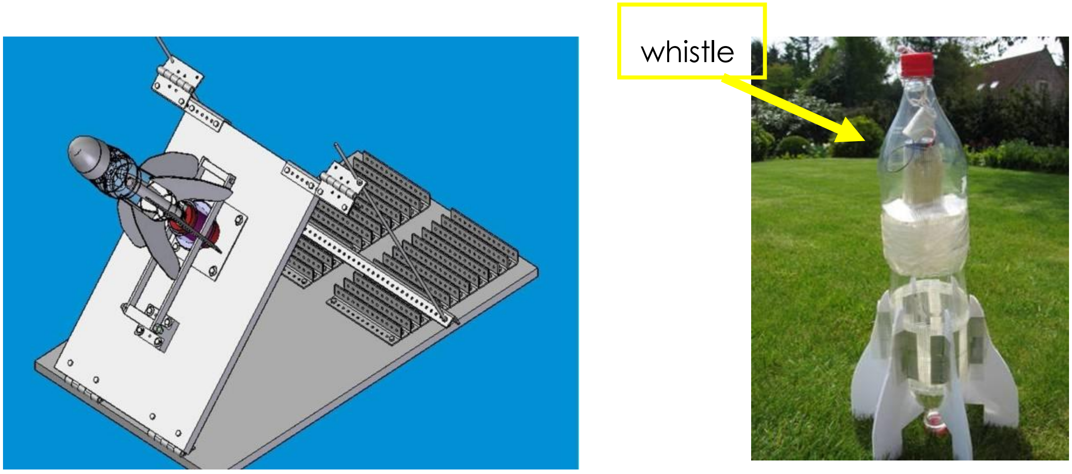
3.2.3.2 Subtask 1: design and build the water rocket and inclination mechanism

The first, most obvious subtask, is the designing and building of the water rocket and launching platform. For safety reasons the launching mechanism is provided for by the didactic team, except for the part to give the rocket an inclination with the perpendicular.

Students apply the simplified linear design process, which was introduced in the beginning of the semester. To start they analyse the instructions and formulate the design specifications. To introduce the financial aspects of engineering design, each team gets only a limited budget for this assignment. To make the assignment hands-on the students build their own designs and prototypes. Because there is no real workshop where the students can work, all designs need to be built using simple materials and simple tools.

Gradually the students discover other conditions for the design of the water rocket. An experiment to measure the drag characteristics of the rocket using Doppler theory is planned to optimise the numerical model. Therefore the water rockets need to have a whistle, with a battery, built in their nose (figure). In the first implementation year this sound-signal was being re-used during the demonstration flights to reconstruct the actual flight path. But using a whistle to measure the trajectory during the demonstration flight outside is proven to be unrealistic. The sound is not loud enough for the microphones to register it from a distance within the environment sounds of for example the wind. As a second system to record the actual flight paths during the demonstrations each flight was also filmed to compare the actual flight with the numerical model. Therefore the rocket's colour is also important, for recognisability on the video-data.

By emphasising the brainstorm phase and asking each team to evaluate at least three different design concepts, creativity is stimulated. The students use Solid Edge to make 3D models and technical drawings of their design (Figure 3-8).



(a) (b)

Figure 3-8. (a) 3D-SolidEdge model of the rocket and launching platform of a student team. (b) water rocket with built-in whistle in the nose.

3.2.3.3 Subtask 2: numerical simulation of the trajectory to optimise the launching parameters

Because the assignment entails a competition, each team needs a numerical model of the trajectory of their rocket to be able to optimise their launching parameters. This competition consists of shooting through the target and landing as far as possible from the launching site. Because the pressure within the rocket is enforced and equal for all teams, the students can still use two parameters to optimise their flight, namely the amount of water in the rocket and the launching angle. To do so they need to understand the rocket's flight and therefore they are encouraged to make a numerical model.

Similar to what they learned in the first semester, while making the numerical model of the experiment, the students first make a schematic overview of the subsequent steps and discuss this with their tutor. In the end they implement the formulas with the

Maple software so the computer model calculates the trajectory of the water rocket based on the characteristics of the rocket and its environment. More in detail the velocity and the position of the rocket is being determined in function of the time.

The trajectory of the water rocket is calculated by means of four subsequent stages, in which other conditions, scientific laws or forces are important (Figure 3-9):

1. launching of the rocket: the rocket is on the launching platform, over the tube;
2. exhaust of water;
3. exhaust of (compressed) air: hypersonic en subsonic phase;
4. free fall.

The initial values of stages 2 to 4, are the end values of the previous stage.

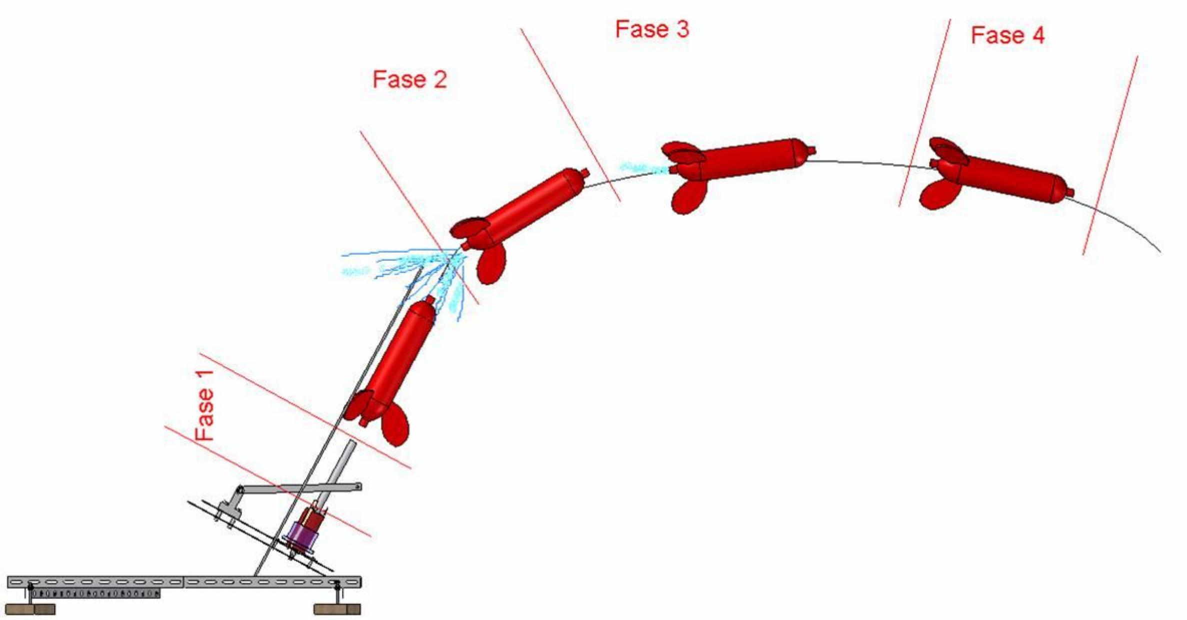


Figure 3-9. Overview of the different stages during the flight of a water rocket. The figure is made by a student team in Dutch. 'Fase' stands for 'stage', so 'Fase1' = Launching of the rocket: the rocket is on the launching platform, over the tube; 'Fase 2' = Exhaust of water; 'Fase 3' = Exhaust of air; 'Fase 4' = Free fall.

The students are encouraged to state clearly the assumptions they make to calculate the velocity in each stage. Table 3-2 gives an overview.

Table 3-2. Overview of the assumptions made to calculate the trajectory of the water rocket.

- The trajectory of the water rocket lies within a plane.
- There is no heat exchange between the water rocket and the environment.
- Use estimated drag characteristics based on the experiment
- Stage 1: launching of the rocket:
  - The friction between the rocket and the launching tube and the air are negligible The launching tube is not hollow, but filled with metal
- Stage 2: exhaust of water:
  - The velocity of the water exhausting the rocket meets the classic Bernoulli law. (The assumption is then made that the rocket moves at a constant speed, which is not the case in reality.)
  - The rocket has a constant cross section. (The narrowing at the end of the rocket is being neglected.)
- Stage 3: exhaust of air:
  - The air in the rocket meets the ideal gas law.
  - The initial temperature in the rocket equals the temperature in the environment (about 25 degrees Celsius).

3.2.3.3.1 Stage 1: launching of the rocket

Stage 1 of the trajectory of the water rocket starts when the rocket is launched by pulling down the handle to loosen the rocket. This stage finishes when the rocket reaches the end point of the launching tube. During this first stage, the expanding air does work to the environment which will be converted into kinetic and potential energy of the water rocket.

This first stage is short, so it is assumed that there will be no heat exchange between the working fluid (the compressed air) and the environment. Therefore the air expansion in the rocket because of the 'removal' of the launching tube can be approximated by using an *adiabatic assumption*:

, = air pressure in the rocket at time t,
= volume of air in the rocket at time t,
— = the adiabatic index, with the specific heat for constant pressure and the specific heat for constant volume,
= a constant.

Due to the changes in the air pressure, the temperature also changes. The following equation expresses the relationship between the temperature and the volume of the air in the rocket during a reversible adiabatic expansion:

— = final temperature of the air in the rocket at the end of stage 1,

= initial temperature of the air in the rocket at the beginning of stage 1,

and = final respectively initial volume of the air in the rocket,

—— , with the specific heat for constant pressure and the specific heat for constant volume.

The student teams apply the *first law of thermodynamics* about the conservation of energy to complete the numerical model of the first stage. The work done by the expanding gas (W) is converted into kinetic ( ) and potential energy ( ) of the rocket:

, with the air pressure in the rocket at time t and the volume of the air in the rocket at time t,

– , with the mass of the rocket and the velocity of the rocket at time t,

, with m the mass of the rocket and h the height of the rocket above the earth surface.

The calculated values for the end of this first stage are inputs for the next stage of the trajectory.

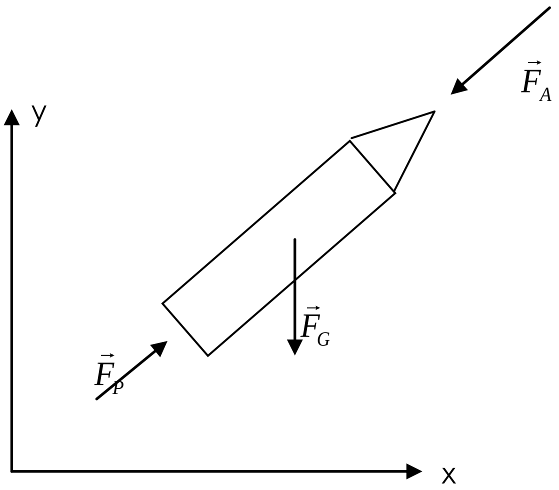
The initial volume of water, and therefore the initial volume of air and the initial mass of the rocket, depends on the choices of the team, including their rocket design. All other parameters are equal for all student teams.

3.2.3.3.2 Stage 2: exhaust of water

During stage 2 of the trajectory, water is being forced out of the rocket by the expanding air. Similarly as in stage 1 the air expansion in the rocket can be approximated by using an adiabatic assumption.

Furthermore the trajectory of the rocket is supposed to be two-dimensional.

The thermodynamic system defined consists of the rocket together with the water and the air. Forces acting on this system are the gravitational force , the propulsion force generated by the exhaust of water and the air resistance (Figure 3-10). Newton's second law of motion can be applied considering the rocket as a point mass in its mass centre.



Newton's second law of motion: $\sum_i \vec{F}_i = m \cdot \vec{a}$, with

$\vec{a}$ = acceleration of the rocket

$\vec{F}_G$ = gravitational force, ,

= total mass of the rocket in function of the time t,

= acceleration of gravity,

$\vec{F}_P$ = propulsive force, —,

= velocity of the exhausted mass of in time t

$\vec{F}_A$ = air resistance,

–

= drag coefficient of the rocket in air,

= cross section of the rocket,

= density of the air,

= velocity of the rocket.

Figure 3-10. Schematic overview of the forces acting on the water rocket in stage 2 (the exhaust of water) and stage 3 (the exhaust of air).

During stage 2 water is being forced out of the rocket by the expanding air. If water flows out of the rocket, the volume of air in the rocket increases.

Similarly as in stage 1 the air expansion in the rocket can be approximated by using an adiabatic assumption.

To calculate the velocity of the exhausting water, which is necessary to compute the propulsive force, the classic law of Bernoulli will be used by approximation. This law applies to non viscous, incompressible fluids in a stationary tube. It will be assumed that the rocket (and the coordinate system attached to it) has with a constant velocity. In reality this is not true. The students can thus build upon their knowledge from the calculations of the vertical launch in the first semester.

Students can re-use what they learned during the first semester about the numerical model of a rocket launch (*assignment 1*) and about calculating the propulsive force generated by the exhaust of mass (*assignment 2*). Therefore portfolios of the first semester are all accessible during the project work of the second semester.

3.2.3.3.3 Stage 3: exhaust of air

Stage 3 starts when all the water is forced out of the rocket. Inside the rocket there is now only compressed air. This stage ends when the pressure of the air in the rocket has dropped until atmospheric pressure.

The third stage can be divided into two separated stages according to the air pressure inside the rocket: chocked gas impulse when the pressure at the outflow gap is above the atmospheric pressure, and sonic gas impulse when the pressure at the outflow gap equals the atmospheric pressure.

1. *Chocked gas impulse*: when the pressure inside the rocket is high enough, it gives rise to a pressure at the outflow gap of the rocket that is above the atmospheric pressure. A shock wave will occur at the outflow gap of the rocket, limiting the exit velocity of the air to the speed of sound.
2. *Sonic gas impulse*: when the air in the rocket is expanded enough to give rise to a pressure at the outflow gap which equals the atmospheric pressure, no shock wave will take place. The gas inside the rocket will expand further adiabatically until atmospheric pressure is equally reached inside the rocket. This is the end of the third stage.

Newton's second law of motion can be applied, considering the rocket as a point mass in its mass centre. Forces acting on the rocket in this stage are the gravitational force , the propulsion force generated by the exhaust of air and the air resistance (Figure 3-10). The initial values are the air pressure and temperature in the rocket at the end of stage 2, when all the water is forced out of the rocket. The volume of air in the rocket is constant in this stage and equals the total internal volume of the rocket.

To calculate the propulsive force, the rate of the exhaust of mass of air can be described in function of the density of the exhausting air and the exit velocity. The density of the exhausting air is not constant; the volume of the air in the rocket is constant and equals the volume of the rocket. The theories that apply in this case, are not known to the students, so the calculation in detail this stage of the trajectory is considered to be 'extra'. Supplementary explanation is given by means of extra instructions and a help-file.

Calculation of the exhaust velocity of the air

To calculate the exhaust velocity of the air at the outflow gap of the rocket in function of the difference between the temperature inside the rocket and the temperature at the outflow gap, two laws are combined:

- the first law of thermodynamics applied to the system of the air inside the rocket (while the heat exchange with the environment and the change in potential energy can be neglected);
- the expression that states that the change in enthalpy of an ideal gas is proportional to the change in temperature (this expression was already used during the combustion and propulsion experiment of the first semester – assignment 2).

Calculation of the air temperature and pressure in the rocket in function

The law for ideal gasses gives a relationship between the pressure in the rocket, the mass of the air inside the rocket and the temperature inside the rocket.

The air expansion in the rocket can be approximated by using a reversible adiabatic assumption, because it is assumed there is no heat exchange between the system (rocket with air) and the environment:

, = pressure in the rocket at time t,
= temperature in the rocket at time t,
— = the adiabatic index, with the specific heat for constant pressure and the specific heat for constant volume,
= a constant.

A relationship between the pressure and temperature inside the rocket and pressure and temperature at the outflow gap can be calculated using the isentropic expansion of the air from inside the rocket to the outflow gap.

, and = pressure at the outflow gap respectively inside the rocket at time t,
and = temperature at the outflow gap respectively inside the rocket at time t,
— = the adiabatic index, with the specific heat for constant pressure and the specific heat for constant volume.

This stage is calculated in two phases: the final values of the initial chocked gas impuls are used to calculate the sonic gas impulse afterwards.

1. Chocked gas impulse: A shock wave will occur at the outflow gap of the rocket, limiting the exit velocity of the air to the speed of sound.
2. Sonic gas impulse: Sonic gas impulse is only possible when the pressure at the outflow gap equals the atmospheric pressure.

3.2.3.3.4 Stage 4: free fall

Newton's second law of motion can be applied, considering the rocket as a point mass in its mass centre. Forces acting on the rocket in this stage are the gravitational force and the air resistance .

Initial values are the end values of the previous stage.

3.2.3.3.5 Optimisation of the launching parameters

A student team chooses the amount of water inside the rocket and the angle a between the launching tube and the horizontal. By using the calculations for the velocity and position of the rocket in function of the time, these two parameters can be optimised by varying them and comparing the (two) goal-parameters:

- in the academic year 2003-2004 the assignment was to fly with the rocket as close as possible to the target with the highest speed
- in 2004-2005 the assignment was to launch the water rocket in a way that it passes as close as possible to the target and lands as far as possible from the launching platform.

- In 2005-2006 all launching were vertically, so only one parameter had to be optimised (the amount of water in the rocket). The goal was to launch as high as possible. Additionally an un-boiled egg had to be taken upwards as payload, and the egg had to land in one piece.

3.2.3.3.6 Summary

The numerical model of the water rocket has a lot of similarities with the calculations in the first semester of assignments 1 and 2. The basic scientific expressions (Newton's second law of motion and the first law of thermodynamics) can be re-used. The mathematical modelling of the water rocket is however more complicated because of the rocket is launched in an angle with the vertical line and because of the movement of the rocket (in assignment 2 of the first semester the vessel was held still).

Students apply Newton's second law of motion, considering the rocket as a point mass in its mass centre. They can re-use the expressions for the forces acting on the rocket: the gravitational force, the propulsion force generated by the exhaust of water or air and the air resistance (Figure 3-10).

The air expansion inside the rocket can be approximated by using an adiabatic assumption (it is assumed that there is no heat exchange between the expanding air and the environment). Furthermore the students apply Bernoulli's law to calculate the exhaust velocity of the water in the second stage. By assuming a reversible adiabatic expansion, the students use the relationships between the temperature, the volume and the pressure of the expanding air to calculate the exhaust velocity of air in the third stage. These formulas are not yet known to the students, so the calculation in detail of this stage of the trajectory is considered to be 'extra'. Supplementary explanation is given by means of extra instructions and a help-file.

3.2.3.4 Subtask 3: free fall experiment to measure the drag characteristics of the water rocket

To make the numerical model of the trajectory of the water rocket as accurate as possible, the drag characteristics of the teams' rocket are important to calculate the air resistance during the flight. For measuring these characteristics, an experimental setup was designed and built. In this setup the rocket makes a vertically free fall downwards. In the nose of the rocket a whistle is located. Based on the Doppler effect; the velocity and the position of the falling rocket can be calculated in function of the time. By applying Doppler Effect, the students integrate the physics course into the team project.

Each team can use the experimental setup for 30 minutes. This time needs to be scheduled within the team project planning.

3.2.3.4.1 Experimental setup

The experiment was set up in the main hall of the 'Thermotechnisch Instituut', where a free fall of approximately 13 meters is possible from the ridge of the roof to the ground floor. After initializing the whistle, the water rocket attached to an electromagnet gets pulled up to the ridge. Right beneath the water rocket a microphone is located within a shaft of mattresses. This shaft is about 2 meters high and protects the microphone from a part of the reflections of the sound waves.

When the measurement is started on the computer, first the sound is recorded without moving the rocket to record the frequency of the whistle's signal. Then the power of the electromagnet will be interrupted manually and the rocket falls down while the microphone records the sound waves produced by the whistle on top of the water rocket.

While doing the experiment, the students are encouraged to accurately fill in a logbook-file, prepared with separate columns for the important parameters and circumstances.

3.2.3.4.2 Data processing

The data was filtered using a relatively narrow band-pass filter because of the known frequency of the whistle. This is done by the didactic team to diminish the noise in the data for the students. Next the frequencies of the whistle (from the first measurement) and the observed frequencies during free fall are calculated from the recorded amplitudes of the audio signal. Starting from these data in function of the time, the velocity of the rocket can be calculated in function of the time, using the formulas for the Doppler Effect for a source that is moving towards the observer:

$$\frac{f_{observed}}{f_{source}} = \frac{c}{c - v_{source}}$$

with $f_{observed}$ the observed frequency when the source (this is the whistle in the nose of the rocket) is moving with a velocity v_{source}; and c the speed of sound. If the source is moving towards the observer, the observed frequency will be higher than the frequency transmitted by the source.

The air resistance force is supposed to be proportional to the square of the velocity of the rocket. Students can estimate the air resistance of their rocket by using the total time of the free fall. It is Important to take into account the reaction time of the electromagnet. Because the total height of the free fall is known, the drag coefficient can be calculated using Newton's second law of motion. Another more accurate method is using a visual fit. In Labview a programme was written to help the students visualise and analyse the measurement data. By varying the drag coefficient students can fit the theoretical model of the free fall by visual comparison on the measured velocity – time graphs (Figure 3-11).

To make sure that the students do this accurately and to stimulate their critical attitude, a table with drag coefficients of common three dimensional objects was added to the instructions. The students were encouraged to check whether their estimated drag coefficient was realistic.

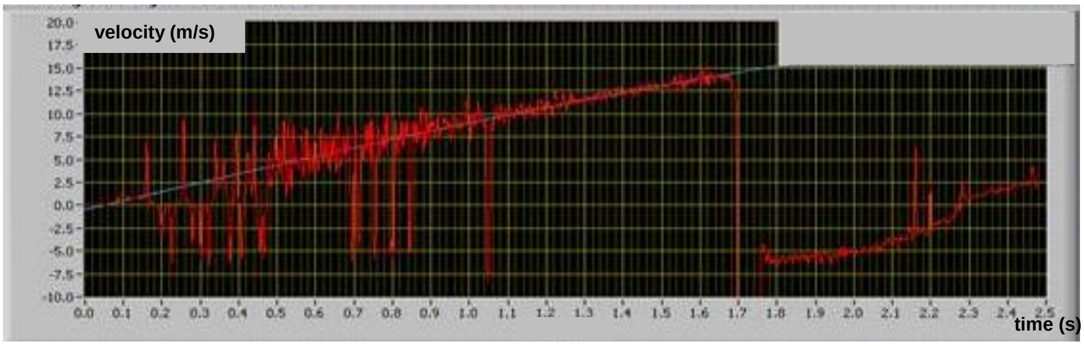


Figure 3-11. With the software Labview the measured velocity – time graphs (the red line) can be fitted visually with a theoretical model (the white line) by varying the drag coefficient. After 1,1 seconds, the measured data shows less noise, due to the shaft of mattresses.

3.2.3.5 Subtask 4: Demonstration

The demonstration flights take place in the seventh week of the project. Each team launches its water rocket using their own inclination mechanism, after filling the rocket with their calculated amount of water and setting up the optimal inclination angle (Figure 3-12). All flights go downwind or upwind to make sure the trajectory of the rocket is two-dimensional.

Each flight is recorded using a video camera and five microphones, spread out the launching place.

Figure 3-12. Preparation (set up with the chosen amount of water and inclination angle with the horizontal) and launching of the team's water rocket to the target.

3.2.3.6 Subtask 5: evaluate the results of the numerical simulation by comparing them to the actual flight

3.2.3.6.1 Preparation

Students are encouraged to prepare beforehand the processing of the data from the actual flight. After the demonstration there is only one team session left, to make this evaluation and finish the report and presentation.

3.2.3.6.2 Videodata

Each flight is filmed. The trajectory of the water rocket is supposed to be two-dimensional. Four reference points are marked for easy recognition in the data and measured for their actual coordinates.

By considering the video data to be subsequent central projections, the actual coordinates of the images can be calculated using matrix transformations. Students can re-use the equations from the third assignment of the first semester (animation) in reversed order to analyse the video-data frame by frame (Figure 3-5). First they rescale the pixel coordinates into coordinates in the projection plane by using two reference points. Next the actual coordinates of the rocket can be calculated by considering the central projection of the rocket onto the plane of projection as the intersection of the projection line through the eye of the camera and the rocket and the projection plane.

The software Vision Assistant of National Instruments helps to define the pixel coordinates of the images. To get a quick result, the students can just use the software and reference points by which the software can make a first rough estimation of the actual coordinates by extrapolation.

Figure 3-13 shows an example of one student team that made a comparison between the trajectory of the rocket calculated from the videodata and the estimated flight based on the numerical model.

3.2.3.6.3 Audio data from the whistle in the top of the water rocket

In the top of the water rocket a whistle is fixed for the measurement of the position during the demonstration flight. Using a whistle to measure the trajectory during the demonstration flight outside is proven to be unrealistic. The sound is not loud enough for the microphones to register it from a distance within the environment sounds of for example the wind.

So in practice the whistle was only used during free fall experiment to measure the drag characteristics of the water rocket.

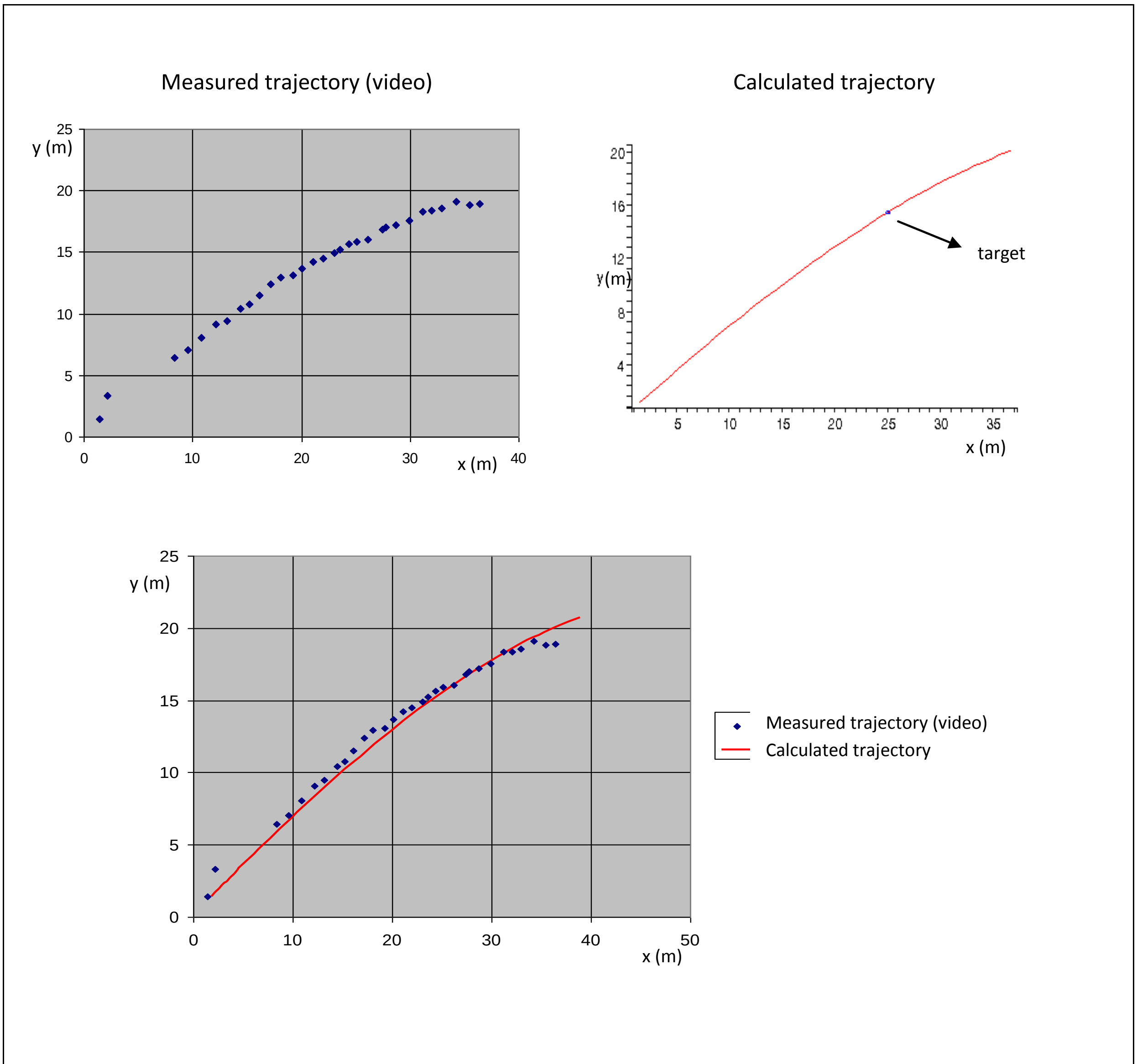


Figure 3-13. Comparison of the position of the water rocket between the videodata and the numerical calculation of a student team.

3.2.3.7 Subtask 6: write a report and give an oral presentation about the project

At the end of the project each team hands in a written report and gives an oral presentation about their project. A template suggests the different topics to discuss (Table 3-3).

Students are explicitly asked to include possible enhancements on the design or on their project.

Two professors are present at each presentation and extensive feedback is given on their presentation techniques.

Table 3-3. Template for the written report and presentation of the design project.

1. Title
2. Problem definition
3. Elaboration:
    - Design of the water rocket
    - Design of the inclination mechanism
    - Drag characteristics of the water rocket
    - Numerical simulation of the trajectory of the water rocket
    - Demonstration flights
    - Comparison of the numerical simulation and the actual flight
4. Conclusion
5. References
6. Appendices

3.2.3.8 Variations on this assignment

Using the same framework of this water rocket assignment, several variations have been tested to minimize the risk of students just copying the work of their predecessors.

Launch to a target

The goal of the water rocket launch was changed each academic year. In 2003-2004 the rockets needed to be pass as close as possible to the target with the highest speed.

In 2004-2005 the rocket needed to pass again as close as possible to the target but by landing as far as possible from the launching platform. This distance was easy to measure on spot and enhanced the sense of competition between the student teams.

Un-boiled egg as payload

In 2005-2006 all launches were vertical. The goal was to launch the water rocket as high as possible. Additionally an un-boiled egg had to be taken upwards as payload, and the egg had to land undamaged. This added a visual element to the demonstrations, which enhanced the sense of competition between the student teams. Additionally, instead of designing the inclination mechanism, the teams designed a mechanism to slow down the package with the egg. Some of the teams used a parachute, other teams just cushioned the impact with the surface. Therefore extra test launches were scheduled before the demonstration flights.

The different alternatives do not alter the project much. The main difference lies in the optimisation parameters related to the design competition. The students need to choose the amount of water inside the rocket and the angle a between the launching tube and the horizontal themselves. By using the calculations for the velocity and position of the rocket in function of the time, these two parameters can be optimised by varying them and comparing the (two) goal-parameters:

- in the academic year 2003-2004 the assignment was to fly with the rocket as close as possible to the target with the highest speed;
- in 2004-2005 the assignment was to launch the water rocket in a way that it passes as closely as possible to the target and lands as far as possible from the launching platform;
- in 2005-2006 all launchings were vertical, so only one parameter had to be optimised (the amount of water in the rocket). The goal was to launch as high as possible. Additionally an un-boiled egg had to be taken upwards as payload, and the egg had to land in one piece. This encouraged the student teams to be more creative and made the assignment a bit more hands-on with more testing of the designs.

3.3 Energy

3.3.1 Introduction

In the academic years 2006-2007, 2007-2008 and 2008-2009 the common technological theme for the course is 'Energy'. This is a topic of great societal and economic interest in today's society and therefore extremely interesting for engineering students. Furthermore this topic combines perfectly the basic scientific courses of the first year of the bachelor.

3.3.2 Introduction to the technological theme

Two engineering lectures are given by prof. W. D'haeseleer and prof. R. Belmans, both professors at the Engineering Faculty of the K.U.Leuven with great expertise concerning energy.

William D'haeseleer is director of the K.U.Leuven Energy Institute; he is chairman of Cogen Vlaanderen, the Flemish association for promotion of high-quality cogeneration, he is chairman of the Energy Section of the Royal Flemish Engineering Association (KVIV) and president of the Belgian Nuclear higher Education Network (BNEN). Prof. W. D. D'haeseleer explained in his lecture with the title 'The issue of a firm energy provision' the terms energy and exergy, long-term scenarios, energy conservation and future challenges: security of supply, clean energy and affordable energy provision. He concluded with the remark that scientists and engineers are necessary to make objective analysis to make a good energy policy possible.

Ronnie Belmans teaches electrical power and energy systems at the Engineering Faculty of the K.U.Leuven. He is chairman of the board of directors of ELIA, the Belgian transmission grid operator. In his lecture prof. R. Belmans explained why electricity is indispensable in society today and tomorrow. It is the driving force of innovation. In the remainder of his lecture he introduces the production of electricity and its distribution through the high-tension network.

3.3.3 Closed assignments of the first semester: 'energy within the student's environment'

3.3.3.1 Literature assignment

3.3.3.1.1 Introduction

Based on the experience of the first three years, the literature assignment was slightly adjusted for the second technological theme 'energy'. The assignment includes an introductory assignment about the terminology used. Furthermore the scientific report should be written starting from a concrete question related to the theme. This implies that the report should be more concrete and to the point.

3.3.3.1.2 Introductory assignment

The introductory assignment consists of the completion of tables and definitions about energy: the definitions and units of energy, energy-content of fuel, work, power, efficiency, different forms of energy, conservation of energy and transformation of energy.

3.3.3.1.3 Scientific report

The assignment consists of writing a short scientific report of about two pages long, starting from a specific energy-related research question. The article should have enough depth and the students need to formulate a conclusion based on the data, gathered from the literature. It is important that they refer correctly and use at least one non-digital source.

Inspiration for topics related to energy can be based on the introductory seminars, newspaper articles and a list of possible topics and ideas on the digital learning environment Toledo (Table 3-4).

Table 3-4. Examples of energy-related research questions for the literature assignment.

- Does a nuclear power station produce ‘clean energy’?
- Am I, as individual, contributing to the increasing CO_2 production?
- Can a family be self-supporting related to their energy balance by a private wind turbine in their garden?
- Will hybrid cars sweep the market?

Students learn to look for relevant literature during a guided tour in the library ‘Campusbibliotheek Arenberg’. A manual explains what is important when writing a scientific text and how to refer correctly to the sources used to write the report. The article template includes all important parts of a scientific report (Table 3-5).

Table 3-5. Template for the scientific report

Title
Abstract
1. Introduction
2. Elaboration
3. Conclusion
References

When a group of two students hands in the scientific report, they fill in a questionnaire to evaluate their work, consisting of three topics:

- The research question (the title needs to reflect the content of the article and is not necessarily the original research question).
- The time spent on gathering information in the literature (and on the internet).
- How the students decided that their sources are reliable.

That way the students are forced to reflect upon their work and think about the reliability of their literature sources.

3.3.3.2 *First team session: orientation and overall assignment*

3.3.3.2.1 Orientation within the technological theme

The title of the first semester is 'Science gives you a boost of energy!'

In the first team session, the students are asked to analyse one day in their life as a student in terms of energy consumption and energy transformation. Furthermore they make the connection with the scientific and technical courses by indicating which technical aspects of these energy-forms and transformations can be explored using theories studied in the courses. Students can build upon the introductory assignment and discuss the schematic overview with their tutor.

The instructions include additional questions to get those teams going that lack initiative (Table 3-6).

Table 3-6. Examples of additional questions to help students analyse one day in a student's life in terms of energy consumption and transformation.

– Make an inventory of energy consuming objects you encounter as a student. – On which form of energy or which energy source are these objects functioning? – Produce these objects directly CO_2 gas? – Which activities in a student's life are most energy consuming? – Possible measures to reduce the energy consumption in daily life? – Possible measures to reduce the CO_2 emission in daily life?

3.3.3.2.2 Overall deliverable of the first semester

The overall deliverable of the semester is a poster (2007-2008 and 2008-2009) or flyer (2006-2007) that demonstrates how the student teams solved the assignments and how they used the basic courses of the first semester to achieve this. The content reflects a research question (see examples in Table 3-7) and the way it was elaborated during the team sessions. Students are encouraged to indicate clearly the applied theories of the other scientific and technical courses. Halfway the semester the students discuss their preliminary design with their tutor.

Table 3-7. Examples of topics for the poster

Energy within the student's environment (Assignment 1)

Energy and electricity:
- How can you shut down big energy consumers in your student house? What are the alternatives?
- What can be done with 1 kWh?

Energy and the human being:
- Compare the energy consumption of a human being with the energy consumption at your student house.
- What are the implications of the CO_2 emissions of mankind on the environment and climate?

Energy and your student house:
- Evaluate the energy consumption in your student house.
- Evaluate the CO2 emissions of your student house.
- How energy efficient is your student house?

Energy and transportation:
- Compare the energy consumption of biking with that of a car.
- Discuss the types of resistance (friction) a vehicle experiences during a ride.

Fuel and propulsion (Assignment 2)
- Make an extrapolation of the experiment toward a real combustion engine.
- Which kinds of fuel are used on daily life? Make a comparison with the experimental set-up.
- Compare the combustion in the experimental set-up with the combustion in the human body.

Animation (Assignment 3)
- Discuss the type of projection used in your animation and evaluate the result.
- Discuss the graphical pipeline: from object to 3D model

3.3.3.3 Assignment 1: energy within the student's environment

Assignment 1 is situated within the student's environment to make the topic 'energy' as real and tangible as possible. This broad theme is divided into four subthemes:
1. energy and electricity,
2. energy and transportation,
3. energy and the human being,
4. energy and your student house.

A team of eight students is divided into four subteams working simultaneously on four sub-assignments. For every sub-assignment the deliverable consists of a short and well-organised report summarising the answers, as well as the methods and applied theories used to solve the problems. This is important because all eight students need to understand the basic principles used to solve all assignments. The students are encouraged to refer clearly to the sources they used while working on the problems.

3.3.3.3.1 Energy and electricity: electrical energy consumption within a student's life

Purpose of this sub-assignment is to make the students familiar with the orders of magnitude of their energy consumption in their student life. By means of an 'energy check meter' they measure the power, or the amount of energy used per unit of time, of a dozen of electric devices. The devices are set up in the design room. Furthermore the students make a list of some additional electric devices they use commonly and search for the corresponding values for the power (Table 3-8).

Some additional small problems are added to the assignment to improve the awareness of the students of their energy consumption, the corresponding energy cost and the work that can be done with for instance 1 kWh (Table 3-9).

This content is not directly an application of the courses of the first semester, but a useful introduction to the theme.

Table 3-8. Examples of electric devices and their corresponding energy consumption in a student's life.

Electric device	**Power (in Watts)**
Notebook – working / stand by	36 W / 20 W
Desktop PC – working / stand by	150 W / 8 W
Computer monitor – working / stand by	38 W / 1 W
Inktjetprinter – printing / standby	11 W / 6 W
Radio (stereo) – working / stand by	23 – 34 W (according to the volume) / 9W
Television – working / stand by	100 W / 12 W
Charger for a GSM – charging	3 W
Coffee maker – working	900 – 1100 W
Toaster – working	950 W
Vacuum cleaner – working	1200 W
Microwave	600 – 1500 W
Electric toothbrush – charging	1 W
Electric shaver – working	10 W
Electric heater – working	1500 W

Table 3-9. Examples of problems to make the students familiar with the orders of magnitude of electrical energy consumption.

Comparing a computer turned off or in standby mode

The students are asked to compare two situations:

1. your computer is turned on for 16 hours each day and the rest of the time in standby mode;
2. your computer is turned on for 5 hours each day and off the remainder of the time.

They calculate the energy consumption and the total price per year, by using a spreadsheet.

What is the cost of one day in a student's life on electricity?

The students estimate the total amount of electrical energy they use in a normal weekday. What is the total cost per student of electricity in one academic year? How much money can you save by using all devices in an energy-conserving manner?

Extra

Calculate for some typical devices how long they can work with 1 kWh. The results can be compared to other energy consuming activities like riding a bike and riding a car (table).

3.3.3.3.2 Energy and transportation

In this sub-assignment the students make some calculations about the common fuels: petrol, diesel and LPG. They calculate the CO_2 emissions, the amount of energy released by the combustion process and the energy content of the fuels (in MJ/l). In doing so the students apply what they have learned in the chemistry-course about chemical reactions, stoichiometry, reaction enthalpy and combustion processes.

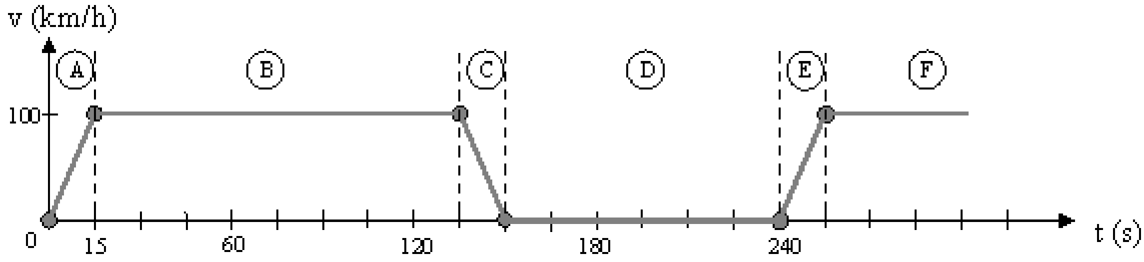
To simplify the calculations the chemical composition can be approached by using octane for petrol, cetane for diesel and a mixture of propane and butane gas for LPG (in summer 40 % propane, in winter 60 %). Then a comparison can be made with the standard values of the energy content for petrol and diesel and the students should draw a conclusion for the approximations used for the chemical compositions. This ensures that the students think critically about their results.

Furthermore the assignment contains examples of car-trips in which the students are asked to calculate the covered distance, velocity and power in function of the time. The students are encouraged to use data from real cars, found on the websites of car manufacturers. These assignments integrate the mechanics course, in which students are asked to make numerical models for movement in function of the time. Calculus is applied to solve the equations. Table 3-10 shows some examples of this type of problems.

Table 3-10. Examples of problems about 'energy and transportation' in which the students make a model of the motion (covered distance and velocity) in function of the time.

Assignment 1

A vehicle accelerates from 0 to 100 km/h in 15 seconds (this is a uniformly accelerated movement). After 2 minutes the car stops at a traffic light: it decelerates to standstill in 15 seconds (a uniformly decelerated movement) and waits for 90 seconds before the lights turn



green again. Suppose there are no resistance forces on the vehicle and it drives at maximum speed.

The total ride takes 5 minutes. Calculate the velocity and the covered distance in function of the time.

Then calculate the work done by the motor if you know that it provides a mean force of 800 N.

Assignment 2

A Toyota Prius from 2006 drives a distance of 100 meters over a rippled surface. The car is driven by a constant power of 10 kW. Suppose the car drives always with an efficiency of 100 %. Make in Maple a calculation of the velocity and covered distance in function of the time. Start from a flat surface and take the rolling and air resistance into account. Refine the model by expressing the rippled surface by using an exponential function.

Assignment 3

A vehicle (represented by a point mass m), that is driven by a motor with a constant power P, drives at a constant speed on a straight line.

- Make a manual sketch of the situation and draw all the forces.
  What kind of resistance forces can a rubber tire in contact with the ground experience?
- Write down a numerical expression for these forces
- Write down a necessary and sufficient condition for the velocity of the vehicle to describe the movement of the vehicle. Interpret the results!

3.3.3.3.3 Energy and the human being

Energy consumption: heart rate monitor

Two members of every team run up and down the stairs for 2 minutes, wearing a heart rate monitor. Every 5 seconds their heart rate is recorded.

Keytel et al. (2005) composed an experimental formula which expresses the energy consumption in function of the measured heart rate, the gender, the weight and the age of a person (Table 3-11). This expression is used as a standard within heart rate monitors like from the 'Polar' company.

Table 3-11. Experimental formula to calculate the energy consumption based on gender, age and heart rate (Keytel et al., 2005).

Energy consumption [kJ/min] = gender × (-55.0969 + 0.6309 × heart rate + 0.1988 × weight + 0.2017 × age) + (1 – gender) × (-20.4022 + 0.4472 × heart rate – 0.1263 × weight + 0.074 × age)
With gender = 1 for men
= 0 for women
Heart rate is expressed in beats per minute.

Students show in a graph their cumulative energy consumption in function of the time and compare the results of the two team members. This shows the dependency of the power on the velocity of the person. Walking the stairs with a high velocity is physically harder, but the work done remains the same. The student who walks the stairs faster supplies a higher power (and can get tired more rapidly).

Intake of energy: combustion of glucose

Humans inhale oxygen and exhale carbon dioxide, produced by the combustion of nutrients with an energy content (fat and carbohydrates). Glucose is the only energy source the human body can use. All carbohydrates (sugars and starch), and to a limited degree also proteins and fats, are transformed by enzymes into glucose before actual combustion takes place.

Students calculate the amount of CO_2 produced by the human body by the combustion of 100 grams glucose. Furthermore they calculate the amount of energy produced by this combustion (reaction enthalpy) and the energy content of glucose (in kJ of kcal per 100 g).

The chemical formula of glucose is $C_6H_{12}O_6$. In the calculation it is assumed that all glucose will be combusted into CO_2 and H_2O. (In reality this is a simplification, because under normal circumstances only the carbohydrates will be combusted in the human body.)

They estimate the amount of energy a student takes in every day via his food. Finally they make an estimation of the 'mechanical efficiency' of the human being by comparing the intake of energy and the performed physical activities. To conclude students are encouraged to reflect upon what happens with the remaining energy.

3.3.3.3.4 Energy and the student's housing

Each team chooses two student rooms to draw up the heat balance. Thermal conductivity, ventilation, sun, internal heat and the room temperature are all taken into account.

A building can be thermally described as a circuit of resistances and capacities. Students take into account the following elements of energy gain and loss:

- the losses by thermal conductivity via the outer wall and the windows;
- the losses by ventilation (In an average room the flow necessary for ventilation is 25 m^3/hour when there is someone present in the room, and 12,5 when the room is not used.;
- the gain of the sun through the glass;
- internal gains of heat by the devices and humans;
- room temperature.

Students search for the formulas in scientific literature and make up the heat balance based on data from their own student rooms, gathered by two of their team members (Table 3-12). Some examples of the questions they can answer based upon this heat balance, could be:

- How much energy is needed to keep the mean room temperature constant and what is the cost?
- How much can you save when you turn down your thermostat with one degree (Celsius)?
- Compare different types of windows.
- Compare the two student rooms.

In this assignment the students learn to search for unknown formulas and apply them to the data they gathered themselves. They are encouraged to think critically about the results and compare two different student rooms.

Table 3-12. Over a period of three weeks two students of each team perform measurements in their student room to gather the necessary data to draw up a heat balance.

The parameters of the student room:

- Area of the outer wall and of the windows
- Type of window (material: wood, PVC, aluminium; single or double glass, low energy glass)
- Type of wall (massive brick wall, hollow wall, metal covering)
- Thickness of the outer wall
- Heating system and fuel used

Students also take a picture of all important characteristics.

The usage of the room:

- The values of individual meters of gas and electricity weekly at a particular time
- The room temperature every morning and every evening
- The amount of hours you are present in your room every day
- An inventory of all energy consuming devices in the room, the power and the time of use during the three weeks.

3.3.3.4 Assignment 2: combustion and propulsion experiment

The second assignment is basically the same as the one used within the theme of ‘aerospace engineering’. The calculation of the propulsion based on the combustion of a fuel fits nicely within this new theme about ‘energy’. The instruction was re-written to emphasise a bit more the energy conversions (chemical energy is converted into the mechanical propulsion force).

This assignment is hands-on and comprises a lot of the course objectives. It requires the application and integration of the different scientific courses: chemistry for the combustion process, mechanics for the forces, calculus for the calculations and differential equations, technical drawing for assembling the experiment, computer tools for using the Maple software. Other objectives incorporated in the assignment are modelling and experimenting (and comparing the results critically), safety, working with measurement data and writing a technical report. Also the practical organisation of this assignment was optimised. Therefore it takes a lot of effort to design an assignment that takes into account all of the above advantages.

3.3.3.5 Assignment 3: animation of a moving car

The third assignment in this theme is also similar to the one in the previous theme. The student teams make an animation video of a moving car using the Maple software. The students can re-use the motion equations drawn up in the first assignment for moving the car.

Students work for two team sessions on this assignment and plan that work independently. Working on this animation, students integrate algebra and mechanics; they use the Maple software and practice their communication and teamworking skills.

3.3.4 Closed design project of the second semester: 'design and build a car that reaches a target on a railway track with minimal energy-input'

3.3.4.1 Overall assignment

The assignment of the second semester is a closed engineering project consisting of the designing and building of a vehicle for travelling on a track on rails to a defined end-point with minimal energy-input. The vehicle starts from a height, with a certain amount of potential energy, and needs to ride up a bigger hill at the end of the track (Figure 3-14). At an optimally chosen moment during the ride, additional energy is needed.

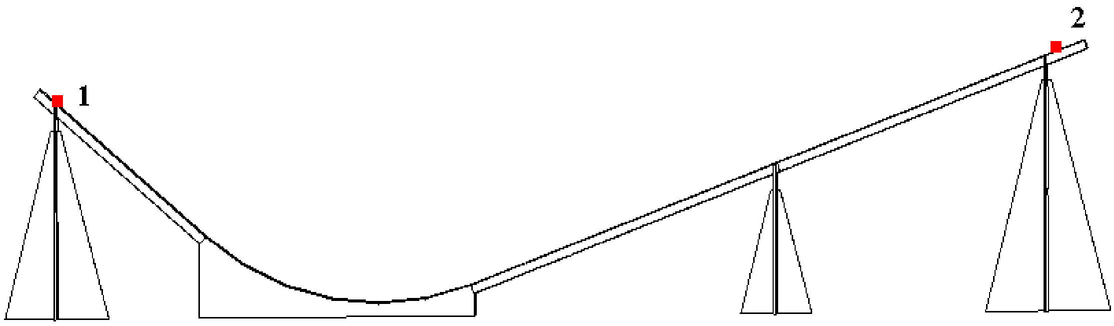


Figure 3-14. The track with (1) the starting point and (2) the end point of the ride.

Students are handed the technical drawings of the track and a fixed budget for building the car of 25 Euros per team.

Student teams can choose almost freely the source for this extra energy. It can be electrical, mechanical, thermodynamical by using compressed air, or a combination of these energy forms.

During the 'energy-race' during the demonstration sessions, each team gets two trials to approach the end-point on the track as close as possible. The exact position of the end-point is given to the students only two weeks before the actual demonstration. This forces the teams to make their set-up adjustable. In this way they are more stimulated to make a numerical model of their ride in function of the amount of extra energy they put in.

After demonstrating their vehicles in 'the energy race', all the teams give a short oral presentation and hand in a written report.

The teams become gradually more responsible for their project design and organise their own work by making a detailed task structure and time schedule. They first spend one afternoon in analysing the task and defining their project planning for the rest of the semester. During the first team session each team discusses its planning with the tutor.

The following subtasks are essential in the task structure:

1. design and building of the vehicle with extra energy input and trigger mechanism;
2. numerical simulation of the trajectory to minimize the amount of extra energy needed and choose the optimal moment to add the extra energy;
3. experiment to measure the friction characteristics of the vehicle (necessary to complete the numerical simulation): air resistance and rolling resistance characteristics are measured;
4. demonstration of the vehicles;
5. evaluation of the results: comparison of the actual trajectories with the numerical simulation;
6. written report and oral presentation.

Table 3-13 gives a general overview of the semester with indication of the milestones.

Table 3-13. Overview of the second semester with indication of milestones.

Session (4hours)	Planned activities	Milestones
1	– Introductory seminar to clarify the assignment – Project planning – Concept sketch of extra energy input and trigger mechanism	– Discuss project planning with tutor – Form with first and second choice for extra energy input
2	– Assigning of extra energy forms – Engineering seminar about mechanical or electrical parts (according to extra energy form) – Teamwork	
3	– Teamwork – From now on each team can test their vehicle each team session on the actual trajectory	
4	– Teamwork	
5	– Experiment for measuring the friction characteristics of the vehicles	– Vehicle (before the experiment) – Premature report: state of affairs – Formative peer assessment
6	– Feedback from tutor on premature report – Feedback from formative peer assessment – Experiment for measuring the friction characteristics of the vehicles	
7	– Teamwork	–
8	– Demonstration days: the energy race (two trials for each team)	– Vehicle with extra energy input and trigger mechanism – Optimalisation of the launching parameters (amount of water and inclination angle)
9	– Evaluation of the actual flight by comparison with the numerical calculations	– Summative peer assessment
10	– Oral presentations – Written test	– Final report – Slides for the presentation

3.3.4.2 Subtask 1: design and build the car

At the end of the first team session, students hand in a form with the concept of their vehicle. The energy input, the form of energy and the way the energy input will start at an optimal chosen moment, are also included in this form. Each team hands in their first and second choice.

Students apply the simplified linear design process, which was introduced at the beginning of the semester. They start by analysing the instructions and formulating the design specifications. To stress the financial aspects of engineering design, each team gets only a limited budget for this assignment (25 Euros). To make the assignment hands-on the students build their own designs and prototypes. Because there is no real workshop where the students can work, all designs need to be built using simple materials and simple tools.

Creativity is stimulated by emphasising the brainstorm phase and asking each team to evaluate at least two different design concepts. The staff decides which teams are entitled to work out their first choices before the second team meeting. They take into account the feasibility, and the limit on only 15 out of 50 teams that can use an electrical circuit due to the availability of these circuits. The second team-session starts with an engineering seminar either about mechanical parts or electronical parts. This helps the students to take a quick start designing their vehicles.

The students use Solid Edge to make 3D models and technical drawings of their design.

3.3.4.3 Subtask 2: numerical simulation of the trajectory to optimise the extra energy-input

Figure 3-15 shows the railway track, fixing the positions of the vehicle. The track can be divided into three parts:

- The first part goes downhill for 1,25 metres with a slope of 40 degrees.
- The second part follows the arc of a circle over a hook of 60 degrees. The radius of the circle is 2 metres.
- The third part goes uphill with a slope of 20 degrees.

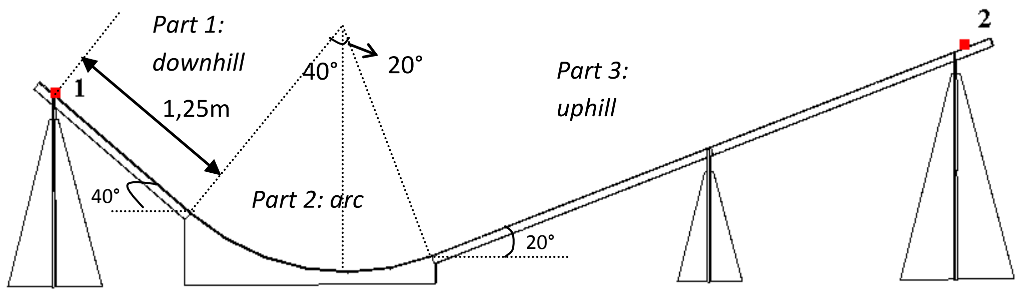
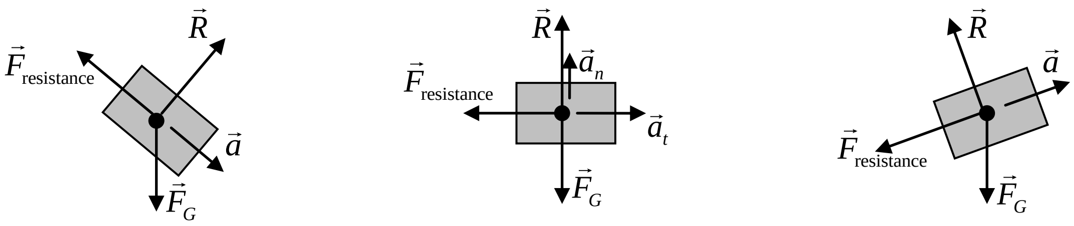


Figure 3-15. Railway track.

At an optimally chosen moment during the ride, additional energy is needed. Therefore the third part of the track is divided into two subparts: the first one without the extra energy source, and the second one after the extra energy input.

The model of the movement of the vehicle can be calculated subsequently for the three different parts (Figure 3-16).

It is assumed that all forces act on the gravity centre of the vehicle.



Part 1: downhill   Part 2: arc   Part 3: uphill

Figure 3-16. Sketch of the forces acting on the vehicle in the three different parts of the railway track.

The differential equation for each part, based on the second law of motion of Newton, with the unknown parameter being the covered distance on the railway track s(t) in function of the time t, includes the following forces:

- the gravitational force , with *m* the mass of the team's vehicle and the acceleration of gravity and
- the resistance force , which includes
  - the rolling resistance with C_r the coefficient of the rolling resistance and the reaction force perpendicular to the track and
  - the air resistance $\vec{F}_{air} = \frac{1}{2} \cdot C_{air} \cdot \rho \cdot A \cdot v(t)^2 \cdot \vec{e}_{F_{air}} = k \cdot v(t)^2 \cdot \vec{e}_{F_{air}}$, with C_{air} the coefficient of the air resistance, ρ the density of the air, *A* the frontal area of the car and the velocity of the car.

It is assumed that the wheels of the vehicle roll over the trajectory. The drag resistance of the wheels is neglected.

The students already are familiar with these forces and expressions from the problems they worked on in the first semester.

The covered distance and the velocity at the beginning of the track (at time t = 0) are initially both 0. The differential equations can be solved subsequently for the three parts, numerically using Maple. That way students can estimate the time that their vehicle needs to travel the two first parts.

The parameters students use from their own designed and built vehicles are:

- mass;
- coefficient of rolling resistance;
- coefficient of air resistance (and frontal area).

At the end of the third part, students can calculate the time and height their vehicle reaches without extra energy input. So they can now also calculate the theoretical minimal energy, needed to overcome the height difference in potential energy to the finish.

While the vehicle moves on the arc of the circle it is important that students realise that the acceleration has a tangential and a normal component. This normal component is needed to calculate the normal reaction force accurately. The rolling resistance in his turn is proportionally to the normal reaction force on the track.

3.3.4.4 Subtask 3: experiment to measure the friction of the car

To make the numerical model of the movement of the car as realistic as possible, an experiment was set-up for measuring the friction characteristics of the teams' vehicles. The experimental setup consists of a straight railway track, which can be placed in different angles (more or less steep). Along this track 16 infrared sensors are placed to measure the moment of passage of the cars. By comparing the theoretical and experimental velocity the friction characteristics can be determined.

The coefficient for the rolling resistance can be calculated by using a very small angle of the track with the horizon. Under those conditions the car drives at a very slow velocity and the air resistance, which is supposed to be proportional to the square of the velocity, can be neglected. At higher angles, the car has a higher velocity and both resistance factors need to be taken into account.

The students start from the raw measurement data and process those themselves using a spreadsheet.

They are encouraged to think critically about their results and compare them to values found in literature.

3.3.4.5 Subtask 4: Demonstration (energy-race)

The demonstrations take place in the seventh week of the project. Each team gets two trials to reach the defined end point as close as possible. There is a jury present to select the best design taking into account the demonstration, the design of the car (creativity and efficiency) and the amount of extra energy input.

Each ride is recorded using a video camera.

3.3.4.6 Subtask 5: evaluate the results of the actual run compared to the numerical simulation

Each demonstration is filmed. The trajectory of the car is fixed by the railway track and therefore known and two-dimensional. Four reference points are marked for easy recognition in the data and measured for their actual coordinates.

By considering the video data to be subsequent central projections, the actual coordinates of the pixels of the trajectory in the images can be calculated using matrix transformations. Students can re-use the equations from the assignment of the first semester to analyse the video-data.

By using the software Vision Assistant of National Instruments, the pixel coordinates of the car in the images can be easily attained. The software can even make an estimation of the actual coordinates.

3.3.4.7 Subtask 6: write a report and give an oral presentation about the project

At the end of the project each team hands in a written report and gives an oral presentation about their project. Students are asked explicitly to include possible enhancements on the design or on their project.

Two professors are present at each presentation and extensive feedback is given on their presentation. This jury gives feedback on the content of the project (by means of what was presented by the team), but also on the students' presentation techniques. With respect to the content of the project, common feedback topics are that students do not stress the results of their project enough, they often avoid to state concrete numbers of measured parameters and they are not always able to formulate critical conclusions on their own work. With respect to the formality of the presentations attention goes to the timing, the presentation slides (if they are clear and readable, the use of figures), the fluent and clear arrangement of topics.

3.4 Summary

The framework described in chapter 2 (Implementation) guarantees that every learning objective is gradually accounted for in the course of the project work. Based upon previous experiences with student design projects and the proposals of the working group of professors of the Engineering Faculty, a first set of assignments related to aerospace engineering was tried out by a pilot team of 8 students during the summer holidays in 2003. Together with the content of the assignments, also the instructional format and the organisation of the course were tested. The actual implementation started in September 2003.

Because of the generic framework, it was possible to define two different sets of assignments for the project work within this thesis. Each set of assignments was situated within a challenging highly technological area familiar to young engineering students and appealing to their imagination. This was made explicit by referring to the media as much as possible. Within the academic years 2003-2004, 2004-2005 and 2005-2006, the course was implemented around the technological theme aerospace engineering. This is an exciting, highly technological theme that was in the media in Belgium around that time because of the flight of the Belgian astronaut Frank De Winne. In the academic year 2006-2007 a second set of assignments was drawn up within another technological theme 'energy'. Sustainability and careful energy consumption is a topic that is really hot at the moment and that inspires a lot of young students.

Because the building blocks for both sets of assignments are the same, part of the student instructions could be re-used because of their generic character (the elaboration of the video-data for example). During the mathematical modelling assignments of the first semester the emphasis is on the course integration and getting familiar with technical skills (the use of the Maple software, information skills, modelling and experimenting) and social competencies (teamworking and communication skills). All generic texts are combined in the P&O manual. In doing so the students can re-use these instructions working on other projects and other professors can refer to the manual as well. For the project of the second semester the student teams work more independently: they define the subtasks themselves and draw up their own project planning. This second project entails a design assignment. To make the related numerical model the students can rely upon the experience of the first semester and re-use the basic theories they have learned to apply. In comparison to the design project related to aerospace engineering the assignment of the second semester within the technological theme 'energy' is formulated in a more open way. Because more diverse solutions are possible (the teams can apply different forms of energy), the assignment stimulates the creativity of the students more. The challenge lies within finding a balance between modelling and experimenting, with the risk of the design becoming the result of trial and error.

Changing the actual assignments regularly is necessary since the students tend to pass on the solutions of their work. Within the technological theme of aerospace engineering, three variants were made for the design assignment of the second semester, so the students couldn't hand in a solution from the previous year. The overall subtasks, problem solving methods and the applied theories however remains the same. So, although they can still find inspiration in the work of earlier teams, they have to understand the chosen problem solving method anyhow in order to apply it to the new situation. Furthermore, changing the whole technological theme gives some fresh air and energy to the didactic theme and to the students.

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4 Evaluation of the course concept

This chapter contains the evaluation of the course implementation characteristics. Section 4.1 discusses the extensive feedback from the students which was gathered by means of extensive questionnaires. Based upon these results the instructional format was evaluated and could be optimised year by year. Section 4.2 summarises the feedback that was obtained through academic audits. In section 4.3 the applied peer assessment procedure is evaluated.

4.1 Evaluation of the implementation characteristics

4.1.1 Introduction

For the evaluation of the course implementation, feedback was obtained from students and from staff involved. The feedback obtained offered opportunities to improve the course concept.

For four subsequent academic years, all first year students enrolled in the course 'Problem Solving and Engineering Design' completed an extensive questionnaire at the end of each semester. The questions were added ad hoc to evaluate and optimise the implementation of the course. Therefore the questionnaires differed slightly every year and every semester. Additionally at the end of each academic year interviews were organised with a limited number of volunteering students. This was done to verify the answers from the questionnaires and to discuss possible changes in the course organisation. Table 4-1 gives an overview of the available data that will be used in the histograms to present the results. Each semester, all 300 to 400 students enrolled in the 'Problem Solving and Engineering Design'-course, filled out the questionnaire. Students were asked to indicate to what extent they agreed upon the statements (1 = strongly disagree; 6 = strongly agree). Only in one occasion, a maximum of 6 % blank answers were counted for the questionnaire in the first semester of the academic year 2005-2006 on a statement for one particular questionnaire. When including all data, the maximum amount of blank answers on a statement is 2 %.

Table 4-1. All students enrolled in a 'Problem Solving and Engineering'-course filled out a questionnaire. This table gives an overview of the course abbreviations that will be used in the histograms to present the results and the number of students who completed the questionnaires.

Academic year	Technological theme	P&O1 Semester 1	P&O2 Semester 2	P&O3 Semester 3 (in the next academic year)
2003-2004	Aerospace engineering	383	408	272
2004-2005	Aerospace engineering	388	378	308
2005-2006	Aerospace engineering	381	363	276
2006-2007	Energy	383	328	/

In this section the feedback of the students will be discussed using the data from the questionnaires. The questions are interpreted one by one because this gives useful feedback to optimise the implementation characteristics of the course.

- Overall mean values were calculated based upon the whole dataset.
- The percentages of students that agreed upon the statements were calculated by taking into account the scores 4, 5 and 6 (rather agree, agree and strongly agree) (Lundberg et al., 2003).
- Histograms are shown using the percentage of answers provided by the students.
- For every statement a one or two way ANOVA was performed, with the agreement on the statement as dependent variable and the semester and/or academic year as independent variable(s), without taking into account the interaction between the two factors semester and academic year (Moore and McCabe, 1997). Significant difference was defined between the mean values when $p < 0,05$.
- Useful ideas from the interviews will be added in the discussions.

To be able to evaluate the course implementation, feedback was obtained related to the integrative concept of the course. The course was created for the purpose of teaching students to combine science, technology and development of competencies. This should orient the engineering studies more clearly to the current engineering profession and relate theory and practice from the first semester onwards. A second set of questions assess the learning objectives of the course; the attainability as well as the students' perceived learning effect. Furthermore feedback was obtained regarding the gradual building up of these competencies within the first year. Finally the students' feedback was obtained with respect to the course organisation: the practical organisation, the clearness of the assignments, the students' time budget, the assessment and guidance of the teamwork.

This chapter discusses the feedback obtained from the students on particular questions. To give a useful summary, only the most interesting results are presented. Based upon these results, the implementation of the course was adjusted every year. More descriptive statistics and more extensive histograms can be found in appendix. In Chapter 5 *The relationship of guidance, perceived learning effects and socio-emotive group quality*, the questionnaires will be analysed and discussed more in detail by means of factor analyses.

4.1.2 Relevance of P&O for the engineering curriculum

'Problem Solving and Engineering Design' was introduced to make the engineering studies more application oriented from the first semester onwards. The students respond enthusiastically. Figure 4-1 shows that they clearly see the added value of this course for their engineering study and they feel teamwork is an enriching experience. The overall mean score on the statement 'Teamwork enriches my education' is 4,69 (s.d. = 0,88; n = 1170). This indicates that the students also acknowledge the importance of working in small groups for their engineering curriculum.

The course introduces the first year students into real engineering practice. The majority of the first year students are interested in the relationship between theoretical principles and the engineering practice (Table 4-2). The students believe that this project based course contributes to their understanding about the application of the theory.

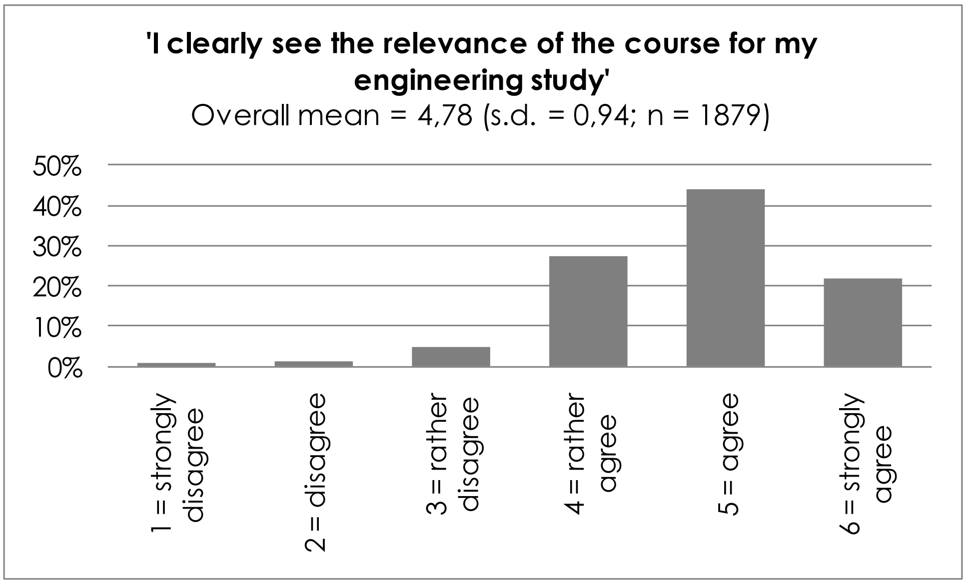


Figure 4-1. Histogram that shows the percentage of students that see the relevance of the course 'Problem Solving and Engineering Design' for their engineering study.

Table 4-2. The majority of the students confirms their interest in the relationship between theory and practice and believes that the teamwork helps to understand this connection.

Statement	**Questionnaire**	**n (number of observations)**	**Mean score**	**Standard deviation**	**Amount of students that agree**
Its relevance for my future profession makes this course fascinating.	P&O1 0607	382	4,38	1,04	84 %
I am interested in the connection of theory and practice.	P&O1 0607	382	4,77	0,88	94 %
The way the teamwork is organised, helps me to understand the connection between theory and practice.	P&O1 0607 P&O2 0607	709	4,43	0,89	89 %

The project is as hands-on as possible. Students appreciate this and 89 % participates actively (see Figure 4-2). Overall mean is 4,38 (s.d. = 0,90; n = 708). This statement was only included in the questionnaire of academic year 2006-2007. There was no significant difference between the first and second semester.

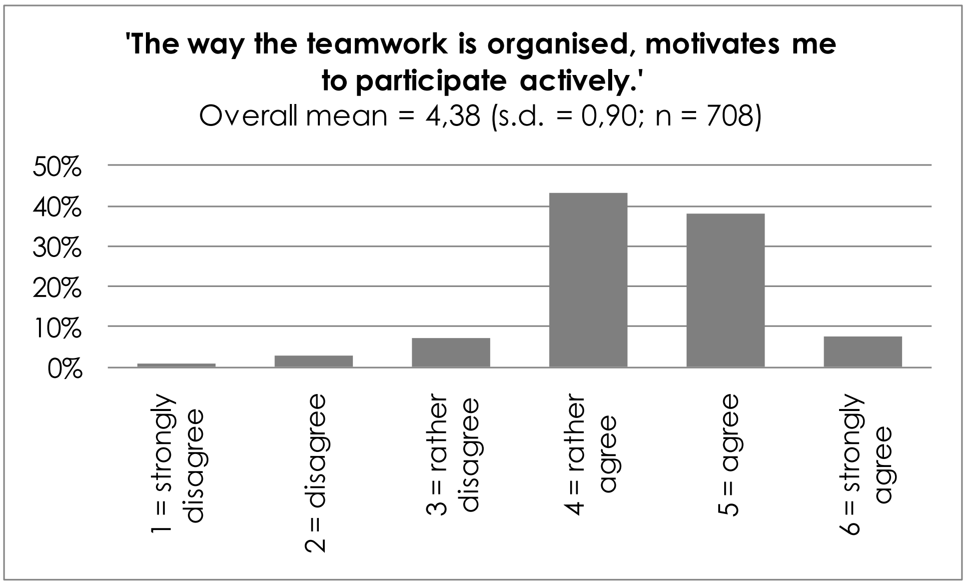


Figure 4-2. Histogram of the response of the students on the statement 'The way the teamwork is organised, motivates me to participate actively'.

4.1.3 Learning objectives

4.1.3.1 Technical competencies

4.1.3.1.1 <u>Course integration</u>

One of the main objectives of 'Problem Solving and Engineering Design' is to demonstrate the relevance and applicability of the basic principles taught in the regular scientific and technical courses. The student feedback confirms that the integration of different courses is necessary to complete the team assignment, with an overall mean score of 4,80 (s.d. = 0,89; n = 2194) for the statement 'I integrated basic principles of different regular courses to complete the team assignment'.

Although the majority of the students clearly see that they need to integrate different courses to complete the team assignment, fewer students are convinced that they have learned more about these basic principles by working in team. The overall mean score on the statement 'Through the teamwork I understand better the basic principles taught in the regular scientific courses' is 4,01 (s.d. = 1,09; n = 2980). There is a significant effect of the semester: in the first implementation year, 2003-2004, the average score for P&O2 was significantly higher. For the following three years, the score for P&O1 was significantly higher. This reflects the effort that was put into improving the course integration. Based upon the results of the first implementation year, the integration of the team assignments with the individual courses has constantly improved (see Table 4-3). Several measures were taken to make students more aware of the importance of understanding the basic principles: the link with the regular coursework is clearly indicated in the project assignment of the first semester and all teams are forced to include short abstracts in their team portfolio to explain the basic theories they apply to solve the assignments.

Table 4-3. Student feedback on course integration. Mean scores on the statement 'Through the teamwork I understand better the basic principles taught in the regular scientific courses'.

Academic year	Mean score in semester 1 (P&O1)	Mean score in semester 2 (P&O2)
2003-2004	3,59 (s.d.=1,16; n = 383)	3,92 (s.d.=1.11; n = 408)
2004-2005	4,06 (s.d.=1,00; n = 388)	3,85 (s.d.=1.06; n = 378)
2005-2006	4,38 (s.d.=1,06; n = 381)	4,05 (s.d.=1.09; n = 363)
2006-2007	4,33 (s.d.=0,96; n = 383)	3,93 (s.d.=1.03; n = 328)

To stress the importance of the course integration objective, at the end of each semester, all students now take an individual test about the content of the project work. In doing so the application of the basic scientific theories within the context of the team assignments is evaluated individually. The test is an open book examination where the students are asked to apply the same principles they used during the teamwork to solve similar problems. The mean scores on this written test reflect the difficulties that the students experience when they need to apply basic principles from the other courses (Table 4-4).

Table 4-4. Mean scores (on 20) on the written individual test at the end of a project.

Academic year	Semester 1 (P&O1)	Semester 2 (P&O2)
2003-2004	(no test organised)	9,8 (s.d. = 3,6)
2004-2005	11,3 (s.d. = 4,5)	10,5 (s.d. = 3,2)
2005-2006	8,4 (s.d. = 3,6)	9,7 (s.d. = 3,4)
2006-2007	11,9 (s.d. = 4,4)	9,1 (s.d. = 3,1)

4.1.3.1.2 <u>Information skills</u>

Students need to master new information while working on the team project (about the subject of the assignment and technological theme of the project, about the numerical calculations in Maple, ...). The data from the questionnaires show that the majority of the students are convinced they have learned to master new information independently, the overall mean score is 4,16 (s.d. = 0,88; n = 2599). There is no significant effect of the semester, but the average result for the academic year 2005-2006 is significantly the highest. This was the third implementation year for the aerospace engineering projects and by that time all assignments were optimized.

Guided tour in the library

Part of the introduction into information competencies takes place during a guided tour in the library in the beginning of the academic year. Despite a literature assignment for which they immediately need to start searching for information and use the tools explained during the tour, the students are not convinced of the usefulness of this tour. 50 % of the interrogated students agreed the guided tour to be useful, overall mean is 3,32 (s.d. = 1,38; n = 769).

4.1.3.1.3 Modelling and experimenting

Engineering lecture about safety

To introduce the first year students into scientific experimenting the following subjects are brought to their attention: the experimental setup, the protocol, the measuring and data processing. In the first semester all teams perform an experiment about combustion and propulsion. This is accompanied by a lecture about safety. Although the lecture was combined with the assignment to draw up a risk analysis of the performed experiment, only half of the students (51 %) are convinced of its usefulness. The overall mean is 3,42 (s.d. = 1,30; n = 768). A possible explanation could be that students are not aware of its importance in the final grading of their results.

Experimenting

In the first semester all teams perform an experiment about combustion and propulsion. In the second semester the design project entails an experiment to measure the characteristics of the designed object and at the end of the semester all teams also demonstrate their design in a small competition. During the demonstration different parameters are measured to evaluate the teams' calculations.

The majority of the students believe these experiments make a useful introduction to performing scientific experiments, overall mean is 4,59 (s.d. = 0,96; n = 1455). This statement was included in the questionnaires in the academic years 2004-2005 (aerospace engineering), 2005-2006 (aerospace engineering) and 2006-2007 (energy). According to the exact assignment they worked on, the students are more convinced of the usefulness of the experiments they did. There is a significant effect of the academic year. The mean for 2005-2006 (4,74; s.d. = 0,93; n = 363) was significantly higher than 2004-2005 (4,54; s.d. = 0,96; n = 765) and 2006-2007 (4,52; s.d. = 0,97; n = 323). In the academic year 2005-2006 more attention was paid to this competency (experimenting). To encourage the students to analyse the data critically, concrete questions about the experimental data-points are added to the assignments. In the second semester of that same year the students experimented a lot more, because a bigger part of the design was solved using trial and error methods. It was the third year of the aerospace engineering theme and the assignment for the second semester was a variation on the water rocket assignment. The teams launched the water rocket vertically with an un-boiled egg as payload. For completing this design, all students experimented a lot more in comparison to the two previous years. Extra launching trials were added to the schedule and each team session the team could test their parachutes by throwing them out of the window at the fourth floor of the building.

4.1.3.1.4 Systematic problem-solving

One of the objectives of the course is to teach the students a systematic way to approach problems. The seven step procedure (Clement et al., 2004) is used as a tool and written instructions help the students to overcome problems they encounter in a systematic way. 88 % of the students believe to have learned a systematic approach to solve problems, overall mean is 4,33 (s.d. = 0,82; n = 1505). Figure 4-3 shows the histogram of this statement.

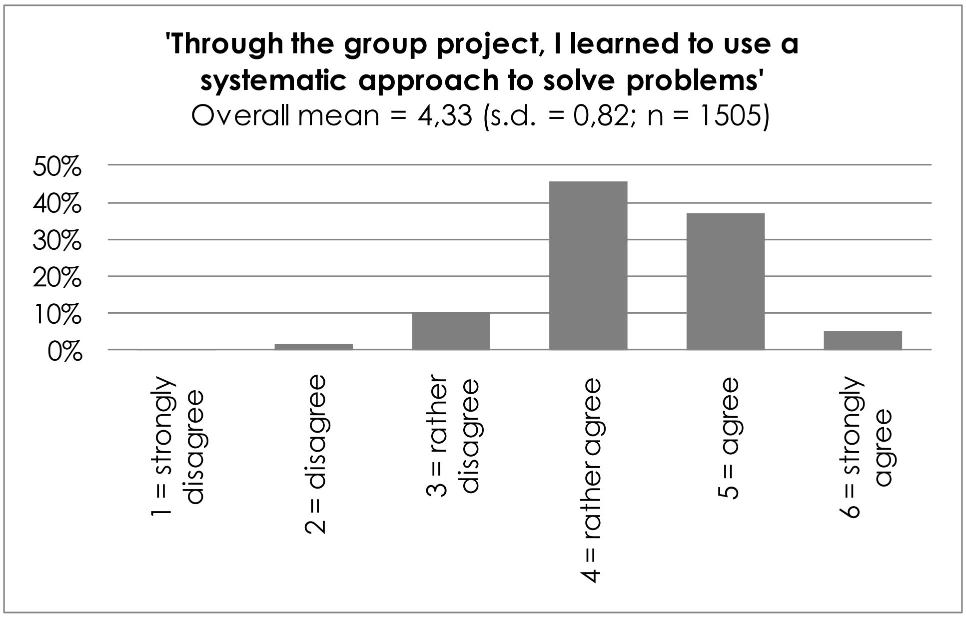


Figure 4-3. Histogram of the answers of the interrogated students about the use of a systematic way to solve problems.

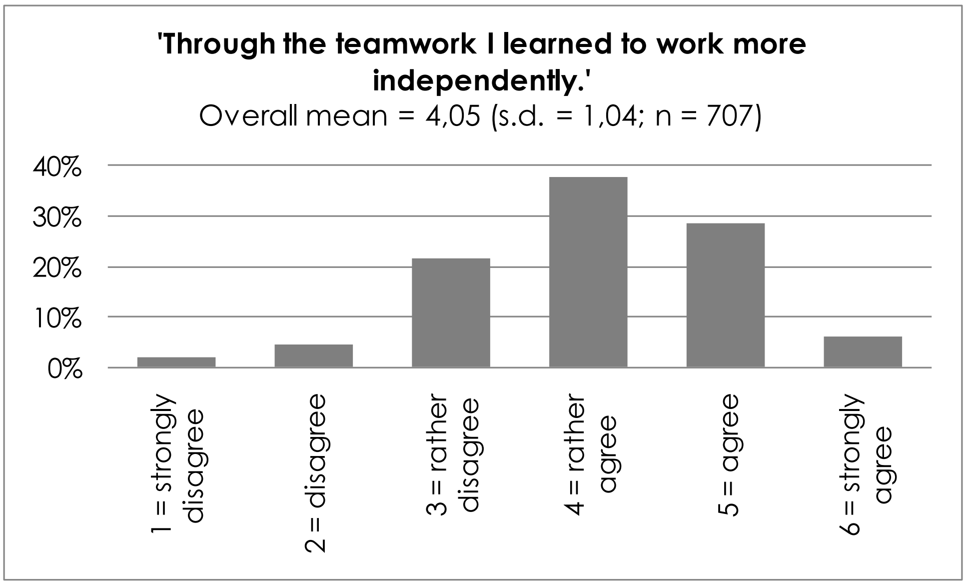
In the second semester students are also introduced to a systematic way of designing and planning their project. Although all teams are forced to use the methods presented in the introductory lecture during their project, students do not really believe they benefit from these lectures.

Overall mean on the statement 'What I learned during the introductory lecture about the design process, helped to complete the team project with a good result' is 3,42 (s.d. = 1,19; n = 1063). This lecture takes place in the second semester, so all data is from the questionnaire at the end of the second project. The average value for the academic year 2006-2007 (3,18; s.d. = 1,13; n = 324) was significantly lower than the others (3,51(s.d. = 1,16; n = 361) in the academic year 2005-2006 and 3,54 (s.d. = 1,07; n = 374) in 2004-2005). For the question 'What I learned during the introductory lecture about the project planning, helped to complete the team project with a good result' the overall mean score is 3,50 (s.d. = 1,18; n = 1066). This lecture also takes place in the second semester, so all data is from the questionnaire at the end of the second project. The score for the academic year 2004-2005 (3,64; s.d. = 1,05; n = 377) was significantly higher than for 2006-2007 (3,32; s.d. = 1,28; n = 324). 2006-2007 was the first implementation year of the new technological theme 'energy'.

These ratings are rather low. The lecture about project planning and systematic designing seems to be very theoretical to the students. They do not see how this lecture can be useful to their project, despite the introduction of small examples in the lectures. In the academic year 2008-2009 a young engineer was invited to clarify the connection between the theory and his every day practice. Students were apparently more interested at that occasion.

4.1.3.2 Attitudes

An objective of the course is to teach the students to work more independently and think critically to evaluate their work. Measures were taken to force the students to reflect upon their activities: each student fills out an individual logbook and self-assessment is a part of the peer assessment procedure. However this can still be improved. Overall mean scores on the statements 'Through the teamwork I learned to work more independently' and 'During the team project I reflected upon my activities to check whether I could improve on something' or 4,05 (s.d. = 1,04; n = 707) and 4,21 (s.d. = 0,90; n = 707) respectively (see Figure 4-4). These questions were only part of the questionnaire in the academic year 2006-2007. There was no significant effect of the semester. Also in the written reports and the presentations of the teams, the didactic staff notices that thinking critically about their own work is hard for the majority of the students.



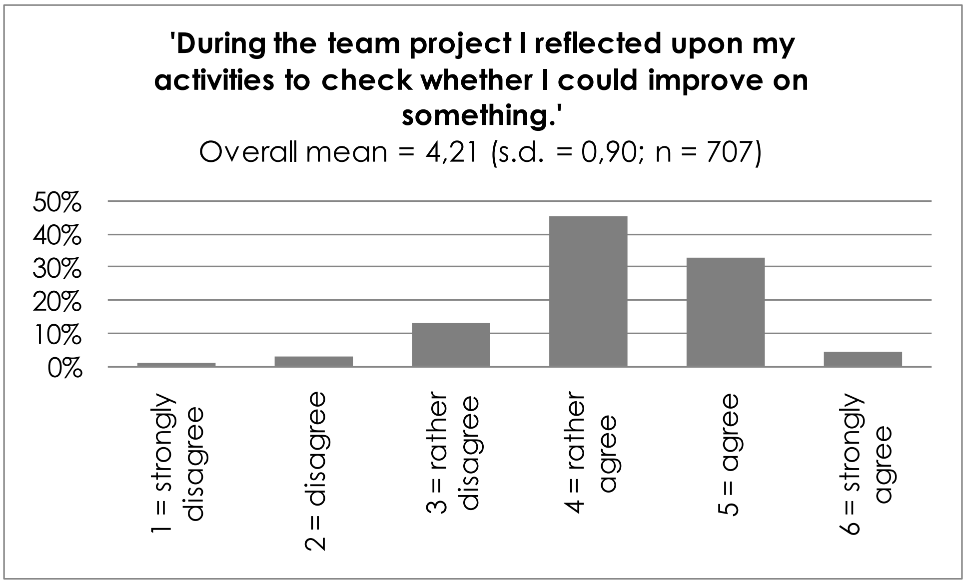


Figure 4-4. Histograms of the feedback of the students about their perception of the learning objectives working independently and reflecting critically.

4.1.3.3 Social skills

4.1.3.3.1 Communication skills

Oral and written communication is an important element in the course. In the first semester students mainly work on written technical reports, on which they get extensive feedback. At the end of the second semester each team hands in a written report on their design project and gives an oral presentation. For practical reasons the questionnaires were filled out before the students gave their oral presentations, so there is no real student feedback about oral communication.

It is the experience of the didactic team that the students find it hard to write a good scientific report. In spite of repeated feedback and reminding the students of their previous errors, they often keep on making the same mistakes over and over again.

In the academic year 2006-2007 statements related to learning how to write technical reports were included in the questionnaire. Overall mean on the question 'The tutors explain the criteria for a good scientific report' is 4,11 (s.d. = 1,11; n = 709). The average of the second semester (4,38; s.d. = 0,95; n = 324) was significantly higher than the mean value of the first project (3,88; s.d. = 1,18; n = 381). This confirms the gradual building up of competencies: students gradually know more about writing scientific reports.

Not all students however believe they have learned how to refer to relevant sources, the overall mean is 3,97 (s.d. = 0,97; n = 709). There is a significant effect of the semester: the mean of P&O1 (4,04; s.d. = 0,92; n = 381) is significantly higher than for P&O2 (3,89; s.d. = 1,01; n = 324). This can be explained by the amount of time students put in their literature study at the beginning of the first semester. In the whole of the first semester more attention goes to external information sources that way that they are more clearly indicated by the didactic team. In the second semester more effort goes to the writing of the report itself.

4.1.3.3.2 Teamworking skills

During the course a lot of attention goes to efficient team functioning. The main focus is on three aspects of teamwork: dividing a team into subteams, the roles of project manager and secretary and organising efficient team meetings. The questionnaires of the first semester included statements to verify to what extend students feel they achieved mastering these competencies.

The majority of the students admit to have learned to work in a team (84 %).

Table 4-5 shows the mean scores of the answers of the interrogated students on the statements that address the different subtasks of working in a team. For most of the sub-competencies about efficient team functioning the mean values were lowest in the academic year 2006-2007. The exception was the statement 'Through the group project, I learned how to divide a team efficiently into subteams.' In 2006-2007 a new technological theme was implemented, as a consequence more attention went to the content of the assignments. Furthermore a member of the didactic team was on pregnancy leave. She had to be replaced by two part time co-workers, as a result some of the teams did not have a fixed tutor for the whole semester.

Table 4-5. Mean scores on statements concerning teamworking skills.

Statement	n (number of observations)	Mean score	Standard deviation
Through the group project, I learned how to work efficiently within a team.	1512	4,27	0,92
Through the group project, I learned how to divide a team efficiently into subteams.	1127	4,36	0,92
Through the group project, I learned about the roles of project manager and secretary of a team	1127	4,32	1,01
Through the group project, I learned how and when to organise efficient team meetings.	1126	4,00	0,97

4.1.4 Gradual building up of competencies

4.1.4.1 Introduction

For the P&O courses a gradual approach in confronting students with technical and social skills was opted for. Within a semester, instruction seminars accompanied by exercises give each individual student the opportunity to master technical skills. In the project work that follows, the students need to apply these competencies together with the gradual building up of social skills. During the second semester, students rely on their experience of the first semester for competencies like systematic problem solving, teamwork, experimenting, communication skills, ...

In a meeting with first year students that was organised in the middle of the second semester of 2006-2007, students indicate they prefer the more open character of P&O2, where they have the freedom to experiment and be on the wrong track for a while.

Towards the third semester, the assignments are more complex and the students become more responsible for their own work. Mastering the necessary competencies during the first and second semester prepares them for the open end design project.

4.1.4.2 Within a semester

In the first semester students learn to make manual sketches and use ICT-tools efficiently through a series of instruction lectures accompanied by exercises. In the second semester they learn how to model objects and processes by using Computer Aided Design software (Solid Edge) and Finite Element Models. These competencies are useful while working on a design project. 80 % of the students agree to have used these technical skills taught in the instruction lectures and exercises, while working on the team project. Overall mean score is 4,26 (s.d. = 1,13; n = 2242).

In the interviews that were organised, the students often indicated that they lack the necessary skills to use the Maple software efficiently during the teamwork. Learning to use this software is the subject of one instruction seminars and two exercises in the first semester. To meet these complaints, the mini-library in the design room now contains reference books to the Maple software. Furthermore the assignments contain extra tips for the maple calculations. Especially in the first semester, templates in Maple help the students to learn how to work with the software.

4.1.4.3 From the first project to the project of the second semester

In the questionnaires of the second semester, students were asked if they had learned more about systematic problem solving and teamworking skills, in comparison to the first project. Students respond positively and confirm the learning improvement (see Table 4-6). For none of the statements a significant effect of the academic year was found.

Table 4-6. Students' perspective on the gradual building up of teamworking skills in the second semester of the course.

Statement	n (number of observations)	Mean score	Standard deviation	Amount of students that agree
Through working on the second project, in comparison with the first semester, I now understand more about a systematic approach to solve problems.	689	4,44	0,94	89 %
What I learned in the first group project about efficient group functioning, helped to get a good result in the second project.	737	4,32	0,97	86 %
Through working on the second project, in comparison with the first semester, I now understand more about dividing a team efficiently into subteams.	1067	4,38	0,94	87 %
Through working on the second project, in comparison with the first semester, I now understand more about the roles of project manager and secretary of a team.	1063	4,08	1,03	75 %
Through working on the second project, in comparison with the first semester, I now understand more about organising efficient team meetings.	1066	4,19	0,98	81 %

4.1.4.4 Preparation for the project of the third semester

At the end of the third project, the students were asked whether what they had learned in the first and second semester, was helpful to them for completing the third design project, which has an open end. In the questionnaire multiple statements were included about several skills: systematic problem solving, team functioning, communication skills, planning of a project and experimenting.

Table 4-7 summarises the students' feedback. Students find that what they learned about systematic problem solving is most useful (overall average of 4,03; s.d. = 1,08; n = 849), and what they learned about performing a scientific experiment did not help them much (overall average of 2,89; s.d. = 1,18; n = 576).

For two of the statements the results after the first implementation year were significantly the lowest. The learning track was subsequently improved by the use of an integrated textbook, to inform the students in a more accurate way about the course concepts and the objectives.

This however needs further attention. During the academic year 2008-2009 more attention went to a detailed briefing of the didactic team involved in the organisation of the third project.

Table 4-7. Student feedback after the project of the third semester on the question that what they learned in the first and second semester helped to get a good result for the project of the third semester.

Statement	**n (number of observations)**	**Mean score**	**Standard deviation**
What I learned in the team projects of the first and second semester about systematic problem solving, helped to get a good result on the project of the third semester.	849	4,03	1,08
What I learned in the team projects of the first and second semester about team functioning, helped to get a good result on the project of the third semester.	845	3,89*	1,19
What I learned in the team projects of the first and second semester about written and oral communication, helped to get a good result on the project of the third semester.	850	3,86*	1,16
What I learned in the team projects of the first and second semester about projectplanning, helped to get a good result on the project of the third semester.	851	3,81	1,17
What I learned in the team projects of the first and second semester about performing a scientific experiment, helped to get a good result on the project of the third semester.	576	2,89	1,18

**There was a significant effect of the academic year. The average result after the first implementation year was significantly the lowest.*

4.1.4.5 Attainability learning objectives

93 % of the students feel that the course objectives are realistic in the first year of their study (overall mean is 4,59; s.d. = 0,86; n = 706). This statement was only included in the academic year 2006-2007. The value for the first semester (4,33; s.d. = 0,85; n = 381) is significantly lower than the mean of the second semester (4,90; s.d. = 0,78; n = 321).

4.1.5 Organisation of the teamwork

4.1.5.1 Practical organisation

Organisation

In total 83 % of the interrogated students agreed the course was well organised. Overall mean is 4,42 (s.d. = 1,01; n = 1499). The effects from the semester and the academic year were both significant. For P&O1, data was gathered in the academic years 2004-2005 (4,49; s.d. = 0,79; n = 387) and 2006-2007 (4,23; s.d. = 1,00; n = 380). The value for 2004-2005 is significantly higher. For P&O2 there are data from 2003-2004 (3,81; s.d. = 1,15; n = 404) and from 2006-2007 (4,48; s.d. = 0,91; n = 324). For P&O2 the latter is significantly higher. This is not surprising because 2003-2004 was the first year the course was organised. The average for the first semester is significantly higher than of the second project. This could be explained by the more open character of the second project.

Design room

The majority of the students agree that the design studios have all the necessary equipment to complete the project well. Overall mean is 4,73 (s.d. = 0,92; n = 782). This also improved significantly from the first implementation year to the second. This statement was only included in the questionnaires of the second semester. The average of the academic year 2004-2005 (4,94; s.d. = 0,81; n = 378) is significantly higher than the average of the first implementation year 2003-2004 (4,54; s.d. = 0,97; n = 404).

Randomly formed teams in the beginning of each semester

Teams are formed randomly by the didactic team. New teams are formed after every project. Students often would like to keep on working with the same team members if the atmosphere within a team is pleasant. Nevertheless, the teams are mixed to encourage the students to learn from other experiences and to start the new semester with a clean slate.

Most of the students agree upon the randomly formed teams (overall mean of 4,72; s.d. = 0,95; n = 1171) and the formation of new teams at the beginning of the second semester (overall mean score of 4,52; s.d. = 1,20; n = 771). For both statements there is a significant effect of the academic year. The average in 2004-2005 is significantly higher than in the first implementation year (2003-2004). This can be explained because more attention went to explaining the reasoning behind the team formation to the students.

4.1.5.2 Clearness of the assignments

Only 59 % of the students agreed that it was always clear for them what was expected for the P&O course (overall mean 3,60; s.d. = 1,16; n = 406). Especially during the lectures, students find it difficult to understand what they should do with it. 83 % of the students agree that it was clear what was expected during the team assignments (overall mean is 4,30; s.d. = 0,90; n = 763). After the first implementation year during every lecture it was emphasised what was the purpose of it and also the manual of P&O described the objectives of the different didactic forms. Since the academic year 2005-2006 a manual is published with all generic documents and guidelines for the generic skills. This manual also clearly states what is expected from the students during the different learning activities. These guidelines are also part of the introductory lecture in the beginning of the semester. Since the academic year 2006-2007 a coloured time schedule visualises the different assignments and deadlines of the first semester.

During the teamwork, more students understand what is expected. However, the overall mean score on the statement ‘The assignments are formulated clearly’ is 3,87 (s.d. = 1,12; n = 709). The average result for the second semester (4,18; s.d. = 0,97; n = 324) was significantly higher than for the first semester (3,60; s.d. = 1,17; n = 381). For teams of eight students to work together at the same time the assignments are extensive. Especially in the first semester a lot of extra tips about the way to solve the problem and the team functioning are included in the assignments. Also the work load needs to remain high enough, especially at the beginning of the first semester. Therefore the assignments are extensive and sometimes require a long time reading. In the hearing that was organised at the end of the academic year 2006-2007, the students indicate they feel they lose a lot of time reading the instructions. On the other hand it is the experience of the didactic team that most of the students do not read them thoroughly enough and ask their tutor later extra questions. This is a problem because the amount of guidance is limited to three tutors for 15 teams of eight students. These tutors have several responsibilities: answering content-related questions, guiding the problem solving process, providing information about the objectives and deliverables, giving feedback and assessing the students. In chapter 5 *The relationship of guidance, perceived learning effects and socio-emotive group quality* the effectiveness of the different tutor responsibilities is being discussed. Because of the limiting resources most effort should be put into the most effective coaching roles.

4.1.5.3 Time budget

In total 57 % of the students feel there was sufficient time provided in the design room to complete the team assignments. The overall mean score is 3,86 (s.d. = 1,36; n = 706). This is rather low.

For both the academic years 2004-2005 and 2006-2007 the average of the second semester was significantly higher than the average of the first semester. Partly this is deliberately done by the didactic team. In the first semester, certainly during the first team sessions, the work load is deliberately rather high. Especially the average result of the first semester in 2006-2007 is really low (2,62; s.d. = 1,10; n = 380). This can be explained by the fact that 2006-2007 was the first implementation year for the new technological theme energy, and one of the tutors was on pregnancy leaf, so the guidance of the students was far from optimal in that first semester.

The Engineering Faculty organised a measurement of the study time of the first year students in the academic year 2007-2008. This showed that the real study time is below the estimated time based on the accounted ECTS credits (see Table 4-8). More information about the study time measurement can be found in appendix.

Table 4-8. Overview of the estimated and measured study time for the course 'Problem Solving and Engineering Design' in the first year of the bachelor of engineering, measured by the working group 'Evaluation of the bachelor' in the academic year 2007-2008.

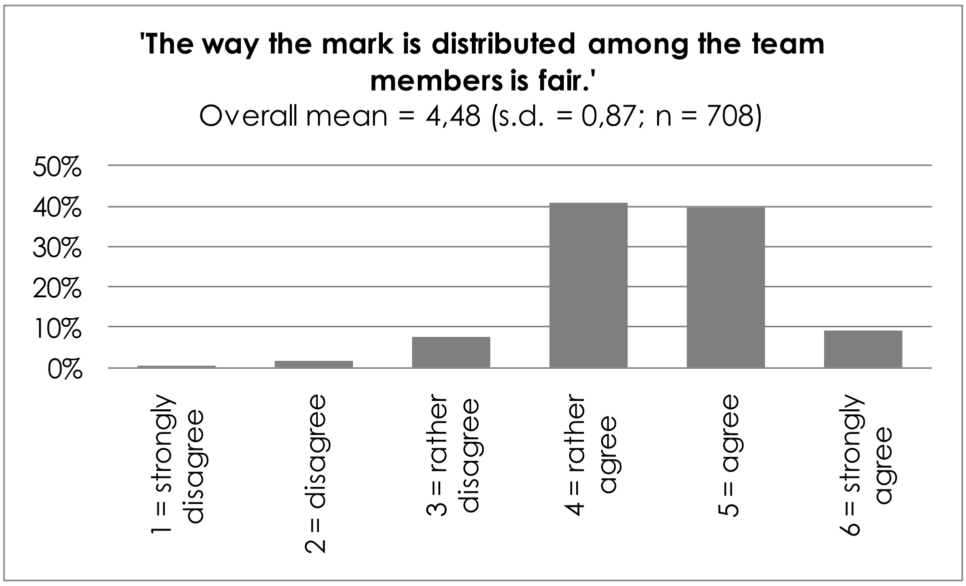
Course	Semester	ECTS credits	Estimated hours	Measured hours (average)	1 ECTS credit (estimated)	1 ECTS credit (average)
Problem Solving and Engineering Design, part 1	1	4	100-120	**92**	25-30	23
Problem Solving and Engineering Design, part 2	2	3	75-90	**64**	25-30	21

4.1.5.4 Student marking

Peer assessment is used for the evaluation of individual contributions to the group assignments. The majority of the students think this is a fair method and consider peer assessment to be a valuable evaluation tool (see Figure 4-5). This was also confirmed during the interview with some students that was organised at the end of the academic year 2003-2004.

Because peer assessment forces students to reflect upon their skills and progress, it offers a great learning opportunity. Not all students feel that completing the peer assessment form contributes to the development of their teamworking skills. The overall mean is 3,40 (s.d. = 1,26; n = 2206). There is a significant effect from the academic year, not for the semester. For semester 1 as well as semester 2 the mean for 2004-2005 is significantly higher than 2005-2006, which is in turn significantly higher than 2006-2007. Possibly during the first implementation years, more effort was put in the explanation of the peer assessment process and its benefits for the students' teamworking skills.

Halfway the semester a formative peer assessment is organised. The feedback that the students obtain individually offers additional information to evaluate their functioning in the team critically. 76 % of the students think this formative feedback is useful (overall mean is 4,22; s.d. = 1,31; n = 1806). For both semesters the average value of the academic year 2006-2007 is significantly the lowest. For the academic years in which this question was asked in both semesters (2005-2006 and 2006-2007), the average value for the second semester was significantly the lowest. This can be explained because most effort in explaining the purpose of peer assessment as well as a good team spirit and team functioning is done in the first semester and less attention went to the team functioning in 2006-2007.



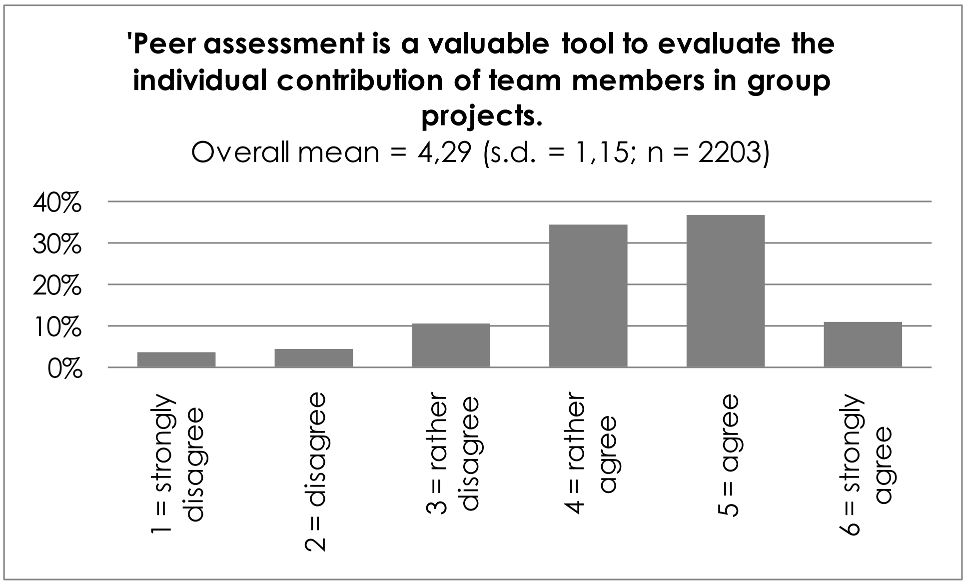


Figure 4-5. Student feedback on the use of peer assessment to evaluate the teamwork.

4.1.5.5 Guidance of the students

The team activities are facilitated by three tutors and two course specialists per fifteen teams of eight students. The didactic team as well as the students feel that this is the absolute minimum for a proper functioning. The overall mean for the statement 'My team could sufficiently rely on tutors and course specialists to complete the team project with a good result' is 3,90 (s.d. = 1,15; n = 2195).

The students find it difficult to accept that tutors do not provide ready-made answers. However, this is implicitly comprised in the course definition: the assignments emphasise self-support and students are confronted with open-end projects. After the first implementation year, the coaching was organised more efficiently by using 'fixed meetings with the tutor' and a reservation list for the course specialists in the second semester. This suggestion was evaluated during the hearing that was organised at the end of the first implementation year (2003-2004). The students present indicated they would appreciate to have a fixed tutor for each team.

In Chapter 5 the different responsibilities of the tutors are evaluated in more detail.

At the end of the academic year 2006-2007, students complained in the interview about the lack of technical staff. The design assignment of the second semester within the 'energy' theme is more hands-on than the rocket-assignments. More teams use tools they are not really familiar with. Technical staff and a workshop are not redundant.

4.1.6 Summary

The above evaluation of the 'Problem Solving and Engineering Design' course is mainly based on questionnaires and interviews of the students and involved staff. They were asked to indicate what they perceived during the coursework. However these self-reported data are not a measure for what really happened, but rather for the perception of the students as to what they believe happened (Thomas, 2000).

However the data gathered give interesting insights into the implementation characteristics of the course and helped to optimise the organisation year by year:

- *In general* students appreciate the integrative concept of the course and see the added value of working collaboratively within a team. The *course integration* however remains a bit of a challenge. Most of the students realise that they used basic theories from different scientific courses to complete the project assignments; but less students are convinced to have learned more about these concepts by applying them. The students confirm the *gradual building up of competencies* They agree they apply the technical skills taught in the instruction lectures with exercises during the teamwork and confirm to have learned more about systematic problem solving and teamworking skills during the second semester in comparison of the first project.
- With respect to the *course organisation* the students indicate that it was not always clear what was expected during the different educational forms. Mainly the lectures (introduction to the technological theme and engineering lectures) and the guided tour in the library seemed to be very theoretical to the students. They are less interested because they do not see the immediate applicability of what is told for their assignments (and grades). The speakers are encouraged to relate the content of their lectures as much as possible with the course assignments and the students' social world. To that purpose lectures experts are invited to broaden the students' perspective and confront them with some technological aspects of their project. This remains a relevant academic objective of the engineering studies.
- 63 % of the interrogated students do not feel there was sufficient time in the design room to complete the team assignments, certainly in the first semester. For a part this is deliberately done to install a good working attitude (especially during the first team sessions). This feeling of the students is however in contrast with the results of a measurement of the study time performed in the academic year 2007-2008.
- The teamwork is facilitated by 3 tutors and 2 course specialists per fifteen teams of eight students. The didactic team as well as the students feel this is the absolute minimum for a proper group functioning. The tutors have several responsibilities: answering content-related questions, guiding the problem solving process, providing information about the objectives and deliverables, giving feedback and assessing the students. In chapter 5 (Research) the effectiveness of the different

tutor responsibilities is being discussed. Because of the limiting resources most effort should be put into the most effective coaching roles.

4.2 Feedback from academic audits

4.2.1 Introduction

To evaluate the course concept the most important question to answer is whether the introduction of P&O really changed the competencies of the graduates. There are several ways to address this. One way is to look at the reports written during curriculum evaluations ('visitation reports'). Since the introduction of P&O in the bachelor program, three academic audits evaluated the curriculum. The comments from the commissions discussed in the next section are translated literally from the Dutch reports that can be found online
(http://www.vlir.be/content1.aspx?PageId=246 - 19/07/2010).

4.2.2 Feedback from three academic audits (2004, 2007 and 2009)

The first evaluation of the concept was performed in 2004 (academic audit of the Mechanical and Electrical Engineering programs). When this evaluation took place, the course 'Problem Solving and Engineering Design' was just implemented in the first year of the curriculum. The visitation report mentions the P&O-course for its orientation to the engineering practice and the way that students are confronted with teamwork, engineering design and research skills this early in their engineering study. Furthermore this offers the students opportunities to learn communication and social skills. The commission shows special appreciation for the P&O course because it integrates an active instructional format with new methods of evaluation (peer assessment and interdisciplinary thinking) and attains that way the academic learning objectives of independence, critical attitude and project planning. The P&O course corresponds well with the educational concept of the university (Guided Independent Learning). Furthermore the course stimulates the students' creativity, enhances teamwork and shows in a highly motivating way the connection between theory and practice. The gradual introduction of competencies and the well-considered building up of active learning methods is appreciated by the commission. 'This educational method is an example for other institutions.'

In 2007 was the next curriculum evaluation organised (academic audit of the Civil Engineering program). The visitiation report mentions the appreciation by the commission and by the students of the large amount of P&O-courses in the curriculum by which the students come into contact with research skills and attitudes from early on in their study. Furthermore the students appreciate the creative manner in which the academic staff defines the P&O assignments.

A third evaluation took place in 2009 (academic audit of the Materials and Chemical Engineering programs). At the time of this evaluation the new curriculum was implemented within all five years of the engineering study. In the report the commission discusses the gradual building up competencies, like research skills and attitudes, in the subsequent P&O-courses. The commission appreciates the continuity of the sessions, starting form guided exercises to more independent work later in the curriculum. The course unites different instructional formats that are well used to attain the objectives of the curriculum. The evaluation of P&O consists of a combination of continuous, oral and written evaluation, which corresponds with the teaching methods and specific learning objectives of the course. The commission thinks this is a good practice and that the evaluation criteria are well announced, among others through the electronic platform Toledo. The students however mention in conversations with the commission that it is not always clear to them which competencies will be evaluated. Furthermore the commission recommends providing more individual feedback to the students regarding their P&O projects.

4.2.3 Discussion

The feedback obtained from the academic audits provides objective information about the implemented P&O-courses from external experts and students. They are merely positive and comment not only on P&O in the bachelor, but the course runs through all five years of the Engineering curriculum. The different commissions appreciate the gradual building-up of competencies, the mixture of instructional formats and evaluation methods and the early confrontation with research skills.

Other ways to perform a more objective evaluation of the effect of the P&O-courses are to gather feedback from the academic staff involved in the master programs, the master students and the graduates. They can however never distinguish between the effects of different aspects of the changed curriculum. No formal evaluation was organised yet, but in informal contacts the promoters from master theses confirm mainly the progress in communication skills.

Furthermore it would be very interesting to get feedback on the new curriculum from young engineers and companies. Because this academic year only the third generation of graduates followed the new curriculum, it is still a bit too early to organise a formal evaluation in the companies.

4.3 Evaluation of the peer assessment method

4.3.1 Introduction

Peer assessment was implemented in the course ‘Problem Solving and Engineering Design’ in the academic year 2004-2005. The experiences are very positive: the students take the evaluation seriously and judge their team members fairly.

4.3.2 Data analysis

4.3.2.1 Identical scores

The results support Kaufman et al. who suggest that the concern about students giving each other identical scores, may be unfounded (Kaufmand et al., 2000). Since the second semester of 2004-2005 five projects were rated using two separate peer assessments: one formatively halfway the project and one summatively at the end of the semester (Table 4-9). Only a maximum of 6 % of the students rated all their team members as ‘average’, namely in the formative peer assessment of the second semester in the academic years 2004-2005 and 2006-2007. For the summative peer assessment only a maximum of 4 % of the students rated all their team members ‘average’ (in the academic year 2004-2005). This is very low and indicates that the students are able and feel confident to give diversified feedback to their team members. Important is that they have the opportunity to learn to evaluate their peers through formative evaluations, guided by members of the didactic team and that the criteria are well known and transparent.

Table 4-9. Overview of peer assessments data for the course ‘Problem Solving and Engineering Design’ for the first semester (P&O1) and second semester (P&O2). The table indicates the number of students that received a formative and summative peer assessment for the project.

Academic year	P&O1	P&O2
2004-2005	/	387
2005-2006	389	371
2006-2007	387	341

4.3.2.2 Validity

The validity of peer assessment can be judged by comparing the peer assessment marks with assessment marks made by the didactic team (Dochy et al., 1999). The statistical results show a significant positive correlation between the total summative peer assessment results and the ratings given by the tutor of a team (Table 4-10). Although not very strong, the Pearson correlation coefficient is about 0,19. The results also correlate significantly with individual test results, but this correlation is also very weak. Because the test was about the content of the project, it is not surprising that individual test results do not correlate with peer assessment marks for ‘quality as a team player’. Figure 4-6 shows a scatter plot of the test results in function of the mark of the summative peer assessment for ‘relevance of contribution’, which has the highest Pearson correlation coefficient (0,24). The plot shows that this correlation is rather weak.

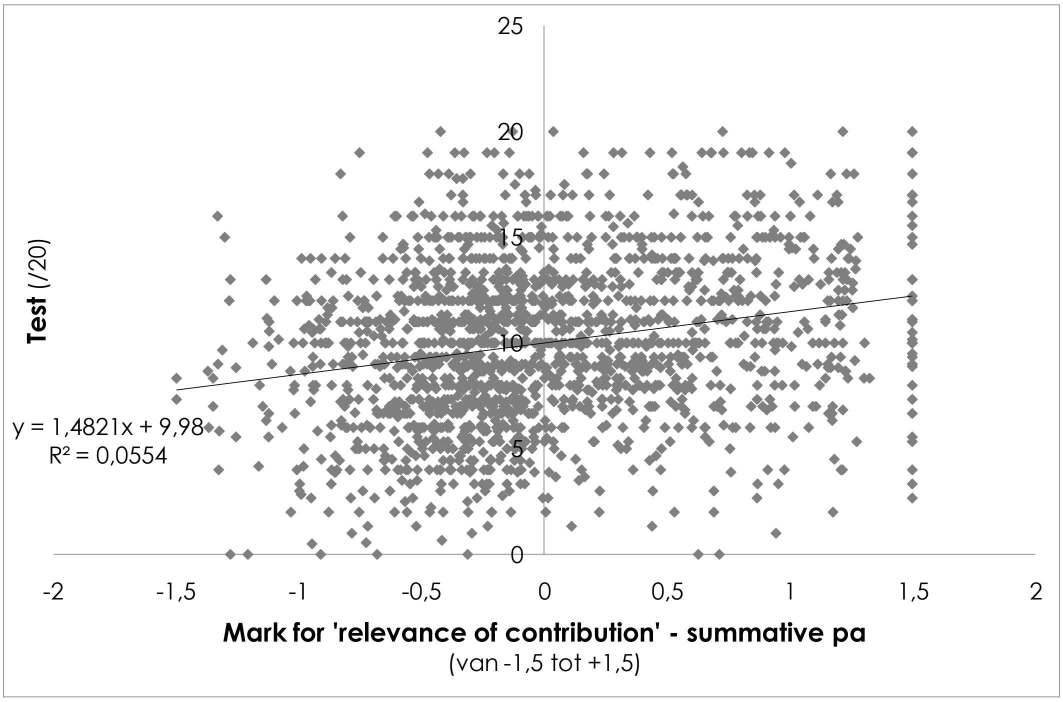
Table 4-10. Statistical analysis of peer assessment results (Moore and McCabe, 1997).

		Pearson correlation coefficient between (p < 0,0001; n = 1850)
Validity	Tutor result – total mark of summative peer assessment	0.19
	Test result – total mark of summative peer assessment	0.20
	Test result – mark of summative peer assessment for ‘relevance of the contribution’	0.24
	Test result – mark of summative peer assessment for ‘amount of work’	0.19
	Test result – mark of summative peer assessment for ‘quality as a team player’	No significant correlation
Reliability	Total mark of formative peer assessment – total mark of summative peer assessment	0.81
	Mark of formative peer assessment for ‘relevance of the contribution’ – mark of summative peer assessment for ‘relevance of the contribution’	0.78
	Mark of formative peer assessment for ‘amount of work’ – mark of summative peer assessment for ‘amount of work’	0.68
	Mark of formative peer assessment for ‘quality as a team player’ – mark of summative peer assessment for ‘quality as a team player’	0.71

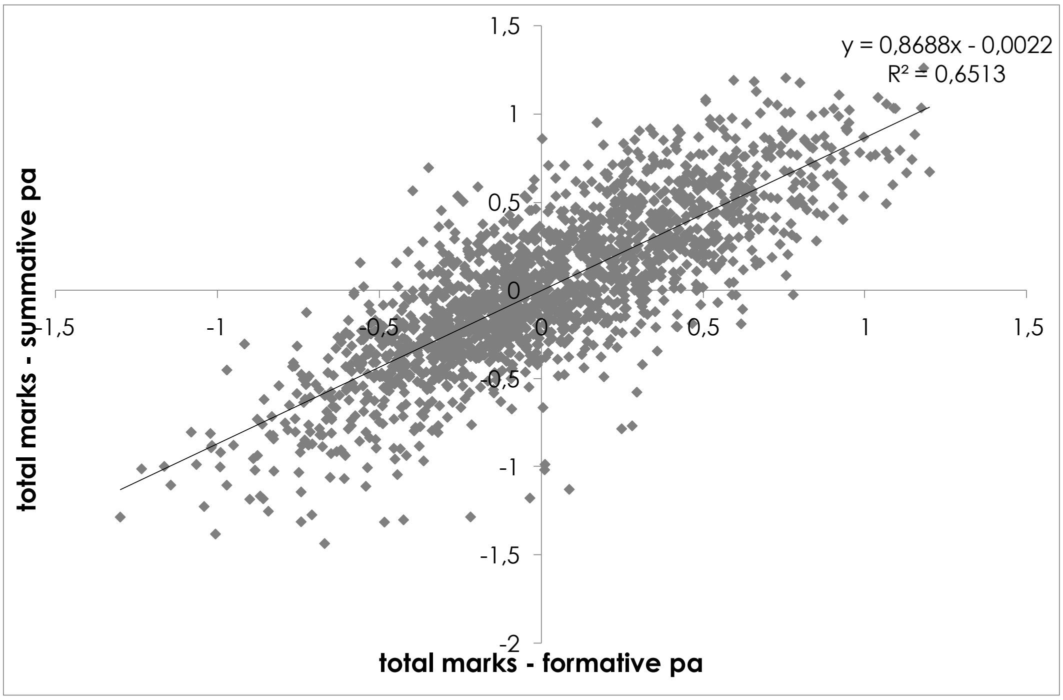
4.3.2.3 Reliability

The reliability of peer assessment results can be explored by comparing results of the same peers over time (Dochy et al., 1999). In 'Problem Solving and Engineering Design' in the first bachelor year, the students judge their team members twice during the same project (the first time in a formative way, the second time summatively). The summative results at the end of a semester correlate well with the formative scores halfway the semester (Table 4-10 and Figure 4-6).

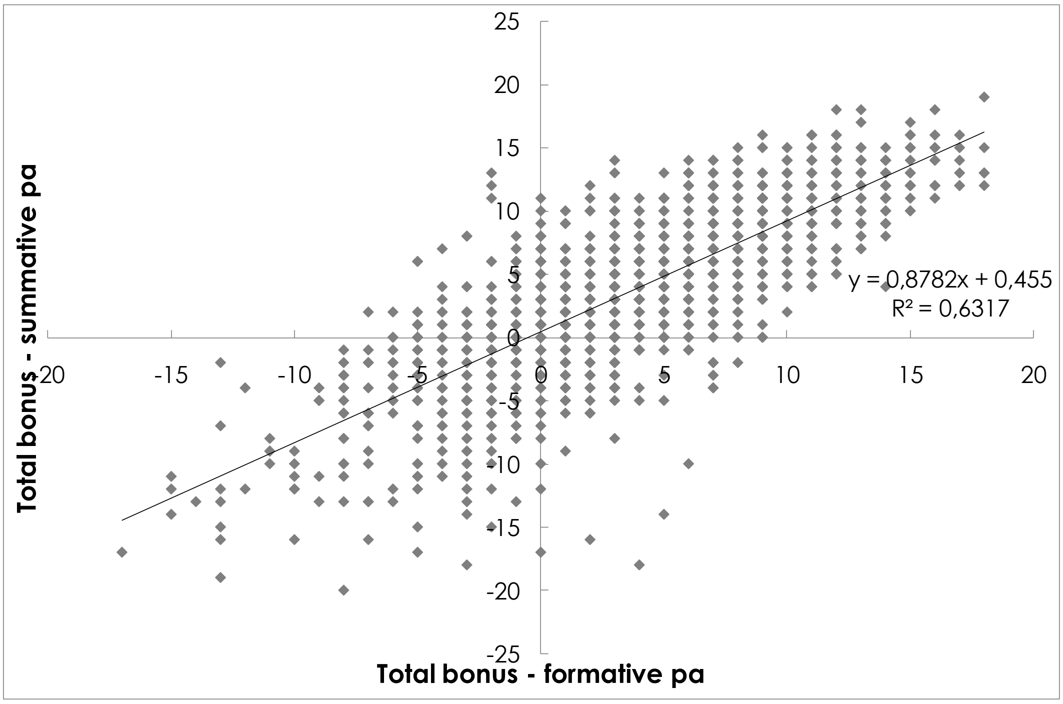
To evaluate whether the students learn from the formative feedback and adjust their team functioning accordingly, Figure 4-6 (c) shows the correlation between the formative and summative peer assessment evaluation by using the raw data (bonuses given by the students). (During the processing of the data, the average is rescaled to one because the students can only evaluate their team members relative to the average of their team.) The scatter plot shows a high correlation, but it does not show a big improvement. Students with a low formative peer assessment do receive a bit higher peer assessment at the end of the semester, but students with a high formative evaluation, get lower scores on their summative evaluation. This can be explained by a kind of migration to the average over time and does not really shows an improvement related to the feedback. However, by means of the questionnaires and in interviews, the students confirm they find the formative peer assessment and feedback useful (Figure 4-7).



(a)

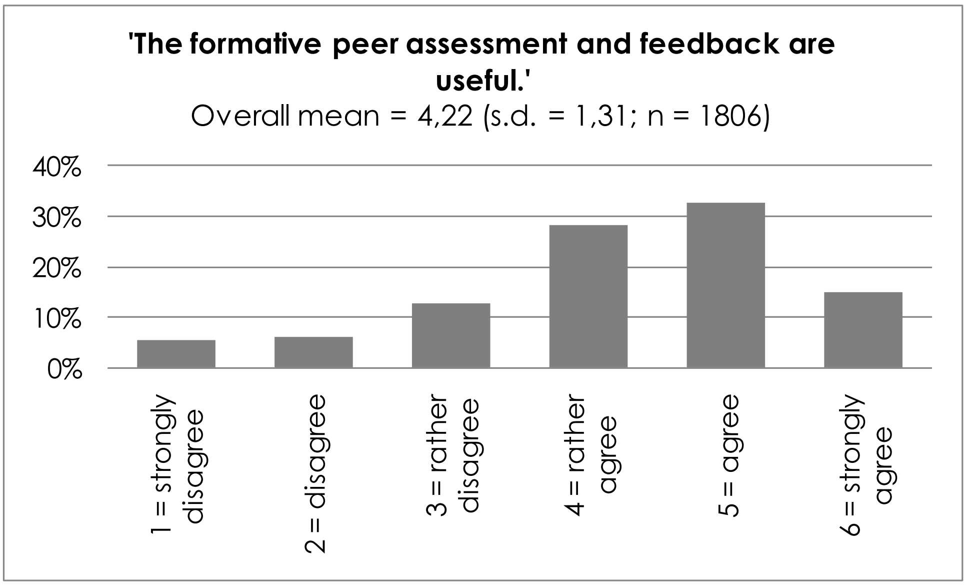


(b)



(c)

Figure 4-6. (a) Scatter plot of the summative peer assessment results for 'relevance of contribution' and the test results: there is a weak correlation between them. (b) Scatter plot of the total summative peer assessment results and the total formative peer assessment results: there is a strong correlation. (c) Scatter plot of the total summative peer assessment results and the total formative peer assessment results by using the raw data (bonuses given by the students to their peers).



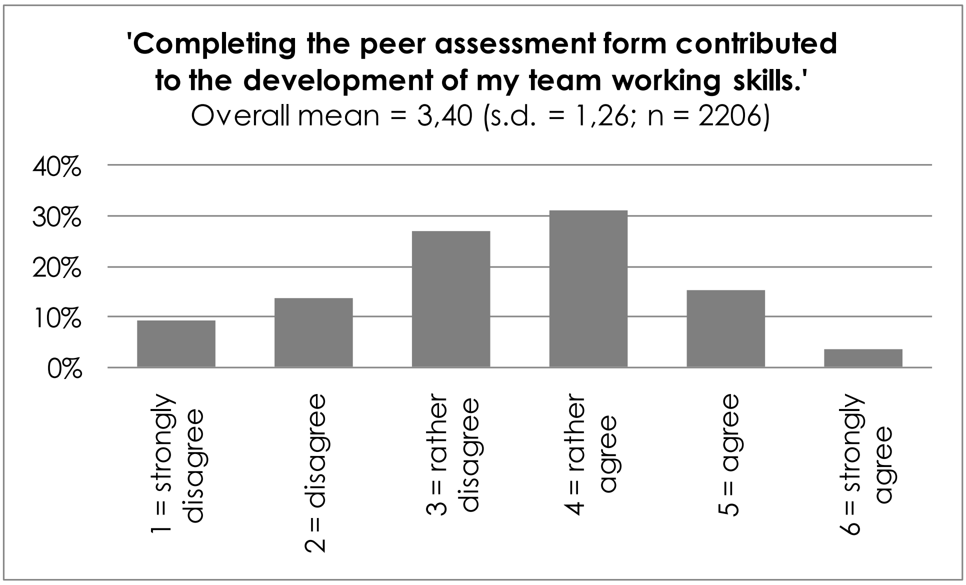


Figure 4-7. Histograms of the feedback obtained from the students by means of a written questionnaire.

4.3.3 Discussion

Peer assessment forces students to make critical evaluations of the relative contributions of their team members. Furthermore through the feedback and the self assessment they are confronted with their own teamworking skills. This offers the opportunity to learn metacognitive skills, which are important for life-long learning (Bostock, 2000).

Peer assessment has been implemented in 'Problem Solving and Engineering Design' since 2004. The results were positive. The majority of the students consider peer assessment to be a valuable evaluation tool for teamwork; they take it seriously and judge their team members fairly. However it is important to coach the students well in the beginning. They need extensive explanation about the goals and criteria of the assessment and sufficient learning time to master the assessment skills. To make the results as accurate as possible the judgements are confidential and the marks are calculated by taking into account different peers and tutor feedback. The correlation between the formative peer assessment results halfway the project and the summative ones at the end of the semester is high indicating a reliable measurement. However, this correlation does not really reveal a positive effect from the feedback that the students receive halfway the project. In spite of this conclusion, the students themselves confirm the usefulness of the formative peer assessment and feedback.

Because of the good results and positive student feedback, peer assessment is currently available for other courses at the Faculty of Engineering. Mainly other teamwork and ‘Problem Solving and Engineering Design’-courses can benefit from this experience. Students expect peer assessment will be part of the evaluation when they perform teamwork assignments. The peer assessment procedure is now used in the mechanics course of the second bachelor year and the P&O course in the third bachelor year at the computer science department.

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5 The relationship of guidance, perceived learning effects and socio-emotive group quality

In this chapter the feedback obtained from the students by means of extensive questionnaires is analysed more in detail.

The teamwork is facilitated by a tutor who has several responsibilities: answering content-related questions, guiding the problem solving process, providing information about the objectives and deliverables, giving feedback and assessing the students. Section 5.1 describes the study of these different guidance tasks in relation to the students' perceived learning effect. By means of factor analyses on the gathered data 'guidance' and 'student learning' scales are constructed. To test the hypothesis that the five defined guidance-tasks have an effect on the student learning, regression analyses were performed.

Buelens et al. observed that the intra-group socio-emotive quality (SEQ) within a team of learners that cooperate for a longer time greatly affects the quality of the final outcome of the project work (Buelens et al., 2005). Within the course 'Problem Solving and Engineering Design' measures are taken for creating a good SEQ. Section 5.2 examines to what extent the level of SEQ within a team of students might be influenced by its members perceived success in bringing (part of) the assignment to a favourable conclusion and in acquiring relevant social skills. By re-assembling the teams each semester, team members are given the opportunity (from the second semester on) to bring in and combine what they have learned during the first and the second project. Therefore it was investigated whether the SEQ of teams improved through the subsequent semesters.

5.1 Guidance and perceived learning effect

5.1.1 Introduction

For the project work, each team is assisted by a *tutor*. He facilitates the teamwork and provides the students with individual feedback on the content of the project, the process of problem-solving and the team functioning. He does not provide ready-made answers, but emphasises self-support.

In addition to the tutors, *course specialists* are invited as experts to explain more in detail the use of the basic principles taught in the regular scientific courses. This supports the course integration, an important objective of 'Problem Solving and Engineering Design'. The course specialists act as experts and they do not know the details of the assignments themselves.

5.1.2 Hypotheses

Based on literature, five guidance-tasks were defined that have an effect on the student learning in a project based course.

1. guidance of the team cooperation (Dolmans, 2005; Johnson et al., 1998; Moust, 2001; Clement et al., 2004; Hansen, 2004; Hmelo-Silver, 2004; Weenk et al., 2004);
2. guidance with respect to the content of the assignments (Clement et al., 2004; Hansen, 2004; Weenk et al., 2004; Moust, 2001);
3. clarifying objectives and evaluation of the course (Johnson et al., 1998; Clement et al., 2004);
4. stimulation of self-activation (Bary and Rees, 2006; Clement et al., 2004; Hansen, 2004; Hmelo-Silver, 2004; Millis, 2002; Woods et al., 2000; Dolmans, 2005; Moust, 2001);
5. providing individual and team feedback (Clement et al., 2004; Hansen, 2004; Rosca, 2005; Dolmans, 2005; Johnson et al., 1998).

In this study it was hypothesized that all these five responsibilities for the guidance of teamwork contribute positively to the student learning.

In addition the tutors of P&O are involved in the evaluation process of the student teams and monitor individual contributions of team members. This last task is not incorporated within this study.

5.1.3 Subjects

During two subsequent academic years (2005-2006 and 2006-2007) several hundreds of students participated in this study. Exact numbers of students are listed in Table 5-1.

Table 5-1. The number of students that participated in the study during two subsequent academic years (from 2005 until 2007).

Year	Moment 1 (= P&O1, Semester 1)	Moment 2 (= P&O2, Semester 2)
3 (= 2005-2006)	381	363
4 (= 2006-2007)	383	324

5.1.4 Material and methods

5.1.4.1 Guidance

At the end of each semester (moment), the students filled out a questionnaire consisting of 34 items measuring the perception of the students concerning the five responsibilities of the tutor and course specialists. Items were constructed based upon the following guidance-tasks:

1. guidance of the team cooperation (7 items);
2. guidance with respect to the content of the assignments (8 items);
3. clarifying objectives and evaluation of the course (8 items);
4. stimulation of self-activation (6 items);
5. providing individual and team feedback (5 items).

A few examples of questions are: 'The tutor explains which results are expected.', 'The tutor encourages us to learn with and from each other.', 'The tutor knows the content of the team assignments well.', 'The tutor motivates our team to look for solutions independently.', 'The tutor formulates individual feedback for individual team members'.

All items were scored on a six-point scale (1 = I strongly disagree; 6 = I strongly agree) and subjected to a principal component analysis with varimax (orthogonal) rotation (Hair et al., 1995). Based on the 'eigen value > 1' criterion five components were retrieved, explaining 59,75 % of the total variance. Five component-based 'guidance' scales were constructed by including all items loading high on the components (>|0.40|). Items loading on two components were excluded. The 'guidance' scales were calculated by summing the scores from included items and dividing this sum by the number of statements composing the scale. The constructed scales correspond generally well with the original guidance-tasks, on which the questionnaire was based. Because the newly constructed scales confirm the classification made on beforehand, the scales can be interpreted well. Theoretical minimum, midpoint and maximum scores on these scales are 1; 3.5 and 6 respectively.

1. The first scale, CB1, is constructed based on 8 items concerning the 'Tutor guidance of team learning and cooperation'. The items loading highest on this component are: 'The tutor encourages us to listen to each other.' and 'The tutor encourages us to respect each other's opinion.' The scale's reliability coefficient is 0.90 (Cronbach's alpha (Hair et al., 1995)). A mean score of 4.20 (s.d. = 0.69) indicates that the students were merely positive about the guidance of the team learning and cooperation by their tutors.
2. The second scale, CB2, is based on 7 items concerning the 'Tutor content related guidance'. The scale's reliability coefficient is 0.91 (Cronbach's alpha). The items contributing most to this scale are: 'The tutor knows the content of the team assignment well.' and 'The tutor is professional enough to provide guidance with respect to the contents.' A mean score of 4.45 (s.d. = 0.80) indicates that the students were overall positive about the guidance with respect to the content of the assignments. During the project work in the design room most of the effort goes to content related guidance. This is mainly due to the amount of content related questions the students tend to ask continuously.

3. The third scale, CB3, is based on 2 items concerning the 'Tutor feedback both to individual students and the group as a whole'. The items loading on this component are: 'The tutor formulates individual feedback for individual team members.', 'The tutor indicates regularly the strengths and weaknesses of our team.' The scale's reliability coefficient is 0.62 (Cronbach's alpha). This relative low reliability coefficient and because the scale is constructed based on only two items, indicates that this scale is not that strong. A mean score of 3.41 (s.d. = 0.93) indicates that providing individual and group feedback can be improved.
4. The fourth scale, CB4, is constructed based on 3 items that concern the 'Tutor information about objectives, expectations and evaluation'. The scale's reliability coefficient is 0.70 (Cronbach's alpha). The mean score is 4.01 (s.d. = 0.77). The items contributing most to this scale are: 'Enough information was supplied about the objectives and evaluation of the course.', 'Enough information is supplied about the assignments and the expected results.'
5. The fifth scale, CB5, is based on 2 items concerning the 'Input of the course specialists'. The scale's reliability coefficient is 0.81 (Cronbach's alpha). The items contributing to this scale are: 'The contribution of the course specialists helps our teamwork progress.', 'The contribution of the course specialists with respect to the content of the assignments is relevant.' A mean score of 4.25 (s.d. = 0.96) indicates that the students appreciate the input of the course specialists as experts, while working in team. In the original classification of guidance-task, these items concerning the course specialists were incorporated in content-related guidance.

The items of the original task 'stimulation of self-activation' contribute to either scale CB1 'tutor guidance of team learning and cooperation', or scale CB2 'tutor content related guidance'.

Table 5-2 gives an overview the five 'guidance' scales. An overview of all items loading on the five components can be found in appendix (Table 7-3).

Table 5-2. Descriptive statistics of the five 'guidance' scales that were constructed based upon a principal component analysis.

Scale		Number of items	Cronbach's Alpha	Mean score	Standard deviation
CB1	Tutor guidance of team learning and cooperation	8	0,90	4,20	0,69
CB2	Tutor content related guidance	7	0,91	4,45	0,80
CB3	Tutor feedback both individual and group	2	0,62	3,41	0,93
CB4	Tutor information about objectives, expectations, evaluation	3	0,70	4,01	0,77
CB5	Input of course specialists	2	0,81	4,25	0,96

Figure 5-1 shows the mean values of the five guidance scales per measurement. The graph confirms that most improvement can be done on scale CB3 about providing individual and team feedback. Figure 5-1 also shows the work that is done on content related guidance and the attention that went to the guidance of team learning and cooperation.

All scales concerning the guidance of the tutor show a minimum in the first semester of the academic year 2006-2007 (Y4M1). This was the first implementation year of the new technological theme, so the tutors were less prepared. This stresses the importance of preparing new project assignments very carefully. Organising a pilot project for a few students is thereby useful. Furthermore in the first semester of that year the guidance of the students was less optimal because of the absence of one of the experienced tutors, who was mostly involved in preparing the assignments. (This minimum is not present in the fifth scale CB5, concerning the input of the course specialists.)

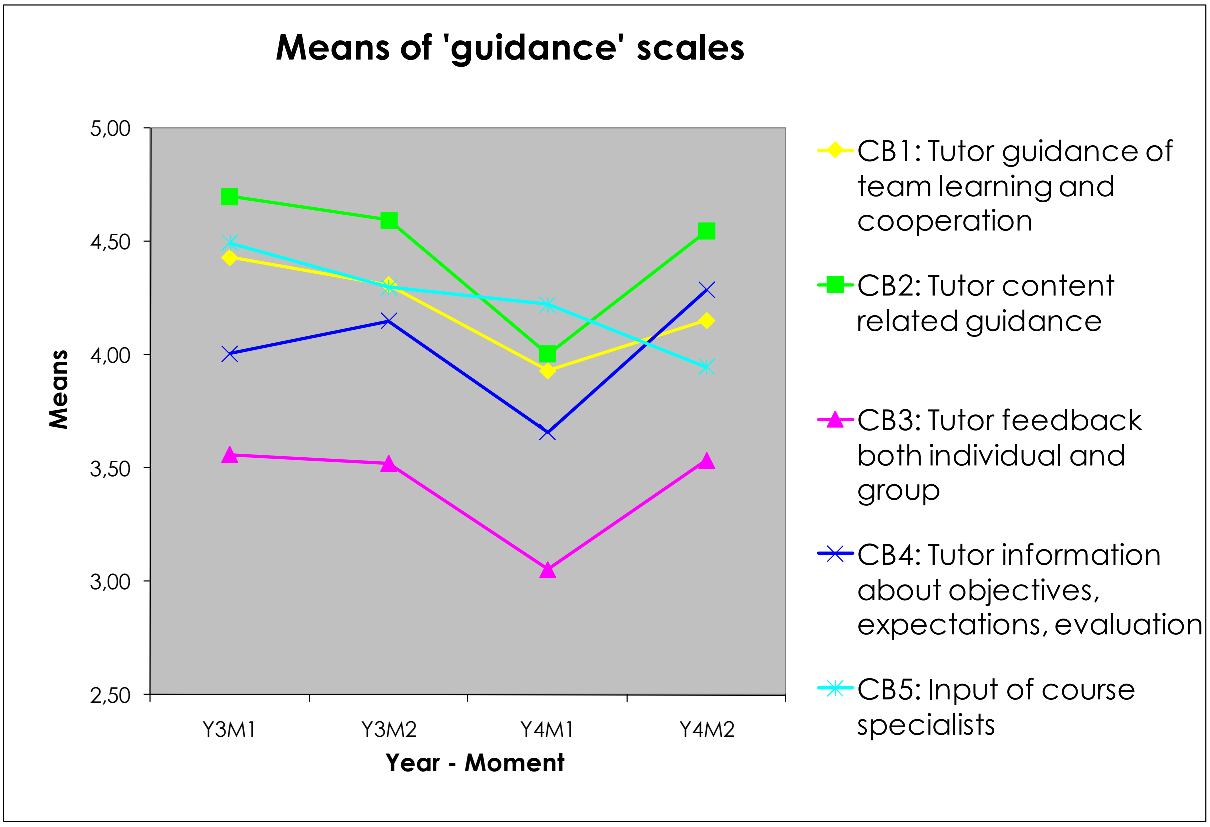

Figure 5-1. Means of the five constructed 'guidance' scales per measurement (Y3 = academic year 2005-2006; Y4 = academic year 2006-2007; M1 = semester 1; M2 = semester 2).

5.1.4.2 Student learning

Together with the 'guidance' questionnaire, students were presented statements about the concept of the course and the perception of their learning (see also section 4.1 *Evaluation of the implementation characteristics*). Feedback was thus obtained from the students about the relevance of the course, the clearness of the assignments, the course integration objective and the gradual building up of technical competencies (systematic problem solving, modelling and experimenting, information skills), attitudes, communication and teamworking skills. All statements were scored on a six-point scale (1 = I strongly disagree; 6 = I strongly agree).

Because these questions were added 'ad hoc' to evaluate and optimise the implementation of the course, the amount and wording of the statements differed slightly each semester. Therefore these data could only be analysed per questionnaire. Per semester a principal component analysis with varimax (orthogonal) rotation was performed, and corresponding component-based scales were constructed based on the 'eigen value > 1' criterion. In total, for the four semesters, seven scales were constructed by including all items loading high on the components (>|0.40|). Items loading on two components were excluded. The constructed scales are meaningful, can be interpreted in several semesters and confirm the classification of the statements made on beforehand. Because of the different questionnaires each semester not all scales are present in every semester and one and the same scale is sometimes constructed based on slightly different statements according to the semester. Meaningful items however load consequently on the same components.

Table 5-3 shows the percentage of variance explained by each principal component analysis and gives an overview of the constructed scales. An overview of the items loading on the components in each semester can be found in appendix (Table 7-4).

Because the newly constructed scales confirm the classification made on beforehand, the scales can be interpreted well. Theoretical minimum, midpoint and maximum scores on these scales are 1; 3.5 and 6 respectively.

1. The first scale 'Clear assignment' only exists in the academic year 2006-2007 and is mainly based on the items: 'The assignments are formulated clearly.' and 'My team could sufficiently rely on tutors and course specialists to complete the team project with a good result.' The reliability coefficients are rather low in both semesters. In the first semester of 2006-2007 the low mean score of 3.68 (s.d. = 0.87) confirms the difficulties that occurred by introducing the new technological theme 'energy' with a new set of assignments and one of the regular tutors absent.
2. The second scale 'Integrative concept and relevance of P&O' was constructed in each semester. Main items contributing are: 'I integrated basic principles of different regular courses to complete the team assignment.', 'Through the teamwork I understand better the basic principles taught in the regular scientific courses.' and 'I clearly see the relevance of the course for my engineering study.' The reliability of the scales and the mean scores are satisfactory in all semesters. The students confirm the added value of P&O for their engineering course.
3. The 'Teamworking skills' scale only exists for P&O1, in the first semester of every academic year. This scale is constructed based on the statements: 'Through the group project, I learned how to divide a team efficiently into subteams.' and 'Through the group project, I learned about the roles of project manager and secretary of a team.' The reliability of the scales are satisfactory and the mean scores indicate that students believe to have mastered teamworking skills while working on their project.
4. The scale 'Contribution to independent learning' is constructed in the two semesters of the academic year 2006-2007, based on the items 'Through the teamwork I learned to work more independently.' and 'Through the teamwork I learned how to master new information independently.' The reliability coefficients indicate a good scale and the mean scores reflect that the students feel they are able to learn more independently through the P&O courses.

5. The next scale 'Transfer of competencies beyond introductory seminar' is based on the statements: 'What I learned during the introductory lecture about the design process, helped to complete the team project with a good result.' and 'What I learned during the introductory lecture about project planning, helped to complete the team project with a good result.' Because these introductory lectures are scheduled in the second semester of each academic year, the scale only exists in two measurement moments. The scale's reliability factors are relatively high, but the mean scores are rather low. This confirms the feeling of the didactic team that the lectures about the design process and project planning are a bit theoretical for the students. They do not see how this lecture can be useful to their project. After introducing small examples in the lectures, in the academic year 2008-2009 a young engineer was invited to clarify the connection between the theory and his every day practice. Students reacted more interested and looked at the engineer like he was 'one of them'.
6. The following scale 'Gradual building up of competencies' is based on statements that were also only part of the questionnaires at the end of the second semester of each academic year. Items loading high on this component are: 'Through working on the second project, in comparison with the first project, I now understand more about dividing a team efficiently into subteams.' and 'Through working on the second project, in comparison with the first project, I now understand more about a systematic approach to solve problems.' The scales' reliability coefficients are satisfactory and the mean scores indicate that students confirm the learning improvement from the first to the second P&O project.
7. The last scale constructed concerns the students' perception of 'Peer assessment'. This scale is based on the items: 'Peer assessment is a valuable tool to evaluate the individual contribution of team members in group projects.', 'The formative peer assessment and feedback are useful.' and 'Completing the peer assessment form contributed to the development of my teamworking skills.' The reliability of the scales is satisfactory. The mean scores are rather low, mainly due to the fact that not all students believe to learn more about team functioning through completing the peer assessment form

Table 5-3. Overview of the 'student learning' scales constructed per semester (horizontal lines). The table contains the percentage of variance explained by each principal component analysis, the original numbers of the items loading high on the constructed scales, the reliability coefficient (Cronbach's alpha) and the mean score of every constructed scale.

			SCALES						
	Variance explained		Clear assign-ment	Integrative concept and relevance of P&O	Teamwor-king skills	Contribu-tion to indepen-dent learning	Transfer of competen-cies beyond introduc-tory seminar	Gradual building up of com-petencies	Peer assess-ment
Y3M1	56,90%	Scale number		C2Y3M1	C1Y3M1				C3Y3M1
		Number of items		2	4				3
		Cronbach's Alpha		0,63	0,72				0,72
		Mean score		4.74 (s.d.=.79)	4.31 (s.d.=0.68)				4.09 (s.d.=0.90)
Y3M2	61,21%	Scale number		C4Y3M2			C2Y3M2	C1Y3M2	C3Y3M2
		Number of items		2			2	7	3
		Cronbach's Alpha		0,72			0,87	0,85	0,74
		Mean score		4.35 (s.d.=0.90)			3.50 (s.d.=1.12)	4.33 (s.d.=0.71)	3.93 (s.d.=1.01)
Y4M1	55,14%	Scale number	C5Y4M1	C1Y4M1	C4Y4M1	C2Y4M1			C3Y4M1
		Number of items	3	9	3	5			3
		Cronbach's Alpha	0,56	0,84	0,68	0,80			0,75
		Mean score	3.68 (s.d.=0.87)	4.53 (s.d.=0.62)	4.34 (s.d.=0.75)	4.11 (s.d.=0.70)			3.77 (s.d.=1.03)
Y4M2	57,32%	Scale number	C6Y4M2	C1Y4M2		C3Y4M2	C4Y4M2	C2Y4M2	C5Y4M2
		Number of items	2	6		4	2	4	4
		Cronbach's Alpha	0,52	0,80		0,74	0,83	0,79	0,65
		Mean score	4.20 (s.d.=0.79)	4.45 (s.d.=0.66)		4.05 (s.d.=0.73)	3.25 (s.d.=1.20)	4.27 (s.d.=0.78)	4.00 (s.d.=0.84)

Scales 2 to 6 refer directly to student learning objectives. Scale 1 concerns the clearness of the assignment and scale 7 is about the evaluation process. Because these two do not measure the student learning directly, scales 1 and 7 will be excluded from the remainder of this study.

To evaluate the results of this perceived student learning measurement, a correlation was made of the remaining five student learning scales with the scores the students obtained for the P&O course. Table 5-4 shows the results for each semester. Besides the Pearson correlation coefficients between the scale and the score on the course per semester, also the partial correlations were calculated (Hair et al., 1995). For this partial correlation correction was made for the academic achievement of the student by correcting for the corrected total end score of the student, this is the end percentage of the student, corrected for the score on the particular P&O-course. The correlations between all courses of the first year of the bachelor are all significant and quite high (between 0,4 and 0,8).

The results show a positive correlation between the score on the course and the students' perspective on the integrative concept and the relevance of P&O. Main items in this scale are: 'I integrated basic principles of different regular courses to complete the team assignment.', 'Through the teamwork I understand better the basic principles taught in the regular scientific courses.' and 'I clearly see the relevance of the course for my engineering study.' Students that agree upon these statements, tend to have better results on the course.

5.1.5 Findings

To test the hypothesis that the five defined guidance-tasks have an effect on the student learning, regression analyses were performed (Hair et al., 1995; Moore and McCabe, 1997). Because the 'student learning' scales are constructed per semester, different regression analyses are performed per semester with the 'student learning' scale as dependent variable and the 'guidance' scales as independent variables.

Table 5-5 shows the partial correlation coefficients for each regression analysis. The numbers show significant correlations ($p < 0.05$). (The explained variance of each regression analysis is reported in appendix (Table 7-5).)

The results confirm the importance for the student learning to provide clear information about the course objectives, the expected results and the evaluation procedure. Scale CB4 'Tutor information about objectives, expectations and evaluation' contributes positively to most of the 'student learning' scales.

Furthermore the results also confirm the significance of coaching the cooperation and team learning. Scale CB1 'Tutor guidance of team learning and cooperation' also correlates positively to all 'student learning' scales.

An interesting observation is the lack of correlation between the 'student learning' scales and CB2 'Tutor content related guidance'. There even seems to be a bit of a negative trend. Mainly when transfer between introductory seminars and subsequent P&O sessions is objected, a negative correlation is revealed. While most of the effort and time of the tutors goes to this task of answering content related questions of the students.

The input of the course specialists however correlates positively with most of the 'student learning' scales. These course specialists provide also guidance related to the content of the assignments, but in theory they do not know the assignments in detail and act as experts. This makes their contribution more relevant with respect to the student learning objectives incorporated in this study.

The latter scale 'Tutor feedback both individual and group' does not reveal any significant correlations. This scale is not very strong.

Table 5-4. Correlations between the student learning scales and the scores the students obtained for the course. Numbers in the table indicate significant correlations (p < 0,05).

Legend of tables 5-4 and 5-5	
	scale does not exists in this semester
	signifant positve correlation (coefficient > 0,200)
	signifant positve correlation (coefficient < 0,200)
	no signifant correlation, correlation coefficient > 0
	no signifant correlation, correlation coefficient < 0
	signifant negative correlation

		SCALE				
Year - Moment		Integrative concept and relevance of P&O	Teamworking skills	Contribution to independent learning	Transfer of competen-cies beyond introductory seminar	Gradual building up of competen-cies
Y3M1	Scale number	C2Y3M1	C1Y3M1			
	Pearson Correlation with score on P&O	0,176	-			
	Partial Correlation with score on P&O by corrected total score	0,142	+			
Y3M2	Scale number	C4Y3M2			C2Y3M2	C1Y3M2
	Pearson Correlation with score on P&O	0,180			+	0,186
	Partial Correlation with score on P&O by corrected total score	0,168			0,127	0,222
Y4M1	Scale number	C1Y4M1	C4Y4M1	C2Y4M1		
	Pearson Correlation with score on P&O	0,148	-	-		
	Partial Correlation with score on P&O by corrected total score	0,137	-	+		
Y4M2	Scale number	C1Y4M2		C3Y4M2	C4Y4M2	C2Y4M2
	Pearson Correlation with score on P&O	+		+	-	+
	Partial Correlation with score on P&O by corrected total score	0,131		+	+	+

Table 5-5. Partial regression coefficients for regression analyses performed per 'student learning' scale per semester ('student learning' scale = dependent variable, 'guidance' scales = independent variables). The numbers in the table are significant partial regression coefficients (p < 0,05).

		SCALE				
		Integrative Concept & Relevance of P&O	Teamworking skills	Contribution to independent learning	Transfer of competen-cies beyond introductory seminar	Transfer of competen-cies beyond p&o sessions
Y3M1	2005-2006 Semester 1	C2Y3M1	C1Y3M1			
Y3M2	2005-2006 Semester 2	C4Y3M2			C2Y3M2	C1Y3M2
Y4M1	2006-2007 Semester 1	C1Y4M1	C4Y4M1	C2Y4M1		
Y4M2	2006-2007 Semester 2	C1Y4M2		C3Y4M2	C4Y4M2	C2Y4M2
INDEPENDENT VARIABLES	CB4	+	0,116			
	Tutor information about	0,267			+	0,282
	objectives, expectations,	0,208	0,118	0,162		
	(Cronbach alpha= 0.70)	0,339		0,208	0,127	0,141
	CB5	0,109	0,163			
	Input of course specialists	0,184			0,125	+
		0,197	0,229	0,188		
	(Cronbach alpha= 0.81)	+	+	-	+	+
	CB2	+	+			
	Tutor content related guidance	-			-	-
		-	-	-		
	(Cronbach alpha= 0.91)	-		-0,143	-0,111	-
	CB1	0,262	0,202			
	Tutor guidance of team learning	0,166			0,145	0,293
	and cooperation	0,103	0,115	+		
	(Cronbach alpha= 0.90)	0,111		0,215	0,186	0,269
	CB3	-	+			
	Tutor feedback both individual	-			+	-
	and group	-	-	+		
	(Cronbach alpha= 0.62)	-		+	+	-

5.1.6 Conclusion

The teamwork is facilitated by three tutors per fifteen teams of eight students. The didactic team as well as the students feel this is the absolute minimum for a proper group functioning. The tutors have several responsibilities: answering content-related questions, guiding the problem solving process, providing information about the objectives and deliverables, giving feedback and assessing the students. Because the limiting resources most effort should be put into the most effective coaching roles.

The results of this study confirm the importance for the student learning to provide clear information about the course objectives, the expected results and the evaluation procedure. Furthermore the results also confirm the significance of coaching the cooperation and team learning.

Interesting is the lack of correlation between the students perceived learning and content related guidance by the tutor. The input of the course specialists however correlates positively with most of the 'student learning' scales. These course specialists provide also guidance related to the content of the assignments, but in theory they do not know the assignments in detail and act as experts. This makes their contribution more relevant with respect to the student learning objectives incorporated in this study.

More research is needed for defining the right time use of the tutors and the effect on the learning experience and learning efficiency of the students. Probably this depends also, at least partially, on the nature of the tutor and his or hers guiding style (more or less directive for example). Also a more objective measurement of the learning outcome of the students is needed.

Based upon the results of this study however, changes could be advised with respect to the guidance of the teamwork by making a clear distinction between the tutor of a team and the course specialists. The tutor explains the objectives of the course, the deadlines and deliverables; he or she coaches the team with respect of the problem solving process and the teamwork and gives feedback. The instructions, the P&O manual, the electronic learning environment and the (mini) library contain information about the problem solving process and the contents of the assignments to help the students solve the problems. The course specialists are experts and the students can ask them concrete questions about the content of the assignments, related to the application of the basic principles taught in the regular courses. It is thereby important that the educational staff do not provide readymade answers, but instead coaches the problem solving process and helps the students to look for the information they need.

5.2 Perceived socio-emotive quality of small group functioning

5.2.1 Introduction

Recently, Buelens et al. observed that the intra-group socio-emotive quality (SEQ) within a team of learners that cooperate for a longer time greatly affects the quality of the final outcome of the project work (Buelens et al., 2005). A good SEQ increases the probability of achieving a good final outcome. A defective SEQ decreases the probability for the group to achieve a valuable final outcome. More importantly however, Buelens et al. also observed that the level of SEQ within a team of co-learners a) is determined very early on in their common history, i.e. after a few meetings, b) remained stable for a very long period (several months) and c) is hard to alter (e.g. intensive coaching of groups with an initial low level of SEQ had no impact at all on subsequent levels of SEQ). As a consequence, a team that does not succeed in establishing a good SEQ at the start, imposes a burden on the remainder of its own future, both in terms of 'getting on with each other' and in terms of reaching a valuable final outcome.

This section examines to what extent the level of SEQ within a team of co-learners might nevertheless be influenced by its members perceived success in both bringing (part of) the assignment to a favourable conclusion and in acquiring relevant social skills. Furthermore we investigate if and to what extent re-assembling teams might be used as a strategy to diminish the occurrence of teams with a bad SEQ.

Each semester teams are reorganised, i.e. new teams are formed at the start of a new project.

5.2.2 Subjects

This study was performed within the course 'Problem Solving and Engineering Design' in the first three semesters of the bachelor of engineering. Each semester students work on a new project. In the course of the three projects a transition from solving well structured, closed engineering problems (first project) to working on open-end design projects (last project) is implemented.

During three subsequent academic years (from 2004 until 2007) several hundreds of students participated in the study. Exact numbers of students and teams are listed in Table 5-6.

Table 5-6. The number of students that participated in the study during three subsequent academic years (from 2004 until 2007).

Project	Year	Number of students	Number of teams
First (P&O1)	1 (2003-2004)	383	47
	2 (2004-2005)	388	52
	3 (2005-2006)	381	47
Second (P&O2)	1 (2003-2004)	408	52
	2 (2004-2005)	378	51
	3 (2005-2006)	363	46
Third (P&O3)	1 (2004-2005)	272	46
	2 (2005-2006)	308	53
	3 (2006-2007)	273	47

5.2.3 Assumptions

We assume that project work allows team members both to learn how to solve complex engineering problems (assumption one) and to acquire social skills (assumption two).

5.2.4 Hypotheses

By re-assembling teams each semester (each project), team members are given the opportunity (from the second project on) to bring in and combine what they have learned (solving complex engineering problems and mastering social skills and competencies) during the first and the second project.

Therefore it was hypothesized that the SEQ of teams will improve through the subsequent projects. Thus, the SEQ of teams will be lowest during the first project and it will be highest during the third project (hypothesis 1A). Stated somewhat differently, it was hypothesized that the number of teams with a (very) low SEQ will diminish over the subsequent projects (hypothesis 1B).

Moreover it was hypothesized that the SEQ of teams at the end of the first project would be a function of its members perceived success in solving (parts of) the first assignment and in acquiring social skills during the first project (hypothesis 2A).

In a like manner it was hypothesized that the SEQ of teams at the end of the second project will be a function of its members perceived success in solving (parts of) the second assignment; and its members perceived success in acquiring social skills during the second project. In addition we hypothesized that during the second project, team members still might benefit from what they have learned during the first project (both in terms of solving complex engineering problems and in terms of mastering social skills). Finally, we thought it plausible that the SEQ of a team during the second project might be influenced by the way team members perceived the SEQ of their first team (hypothesis 2B).

Finally it was hypothesized that the SEQ of teams at the end of the third project would be a function of a) its members perceived success in solving (parts of) both the first, the second and the third assignment; b) its members perceived success in acquiring social skills during both the first, the second and the third project; c) the way team members perceived the SEQ of their first and their second team (hypothesis 2C).

5.2.5 Material and methods

The intra-group SEQ was measured for all project teams in the first three semesters of the course 'Problem Solving and Engineering Design'. At the end of each semester (project) students filled out a questionnaire consisting of 57 items, sampled from existing scales measuring different aspects of socio-emotive quality of group work. Items were retrieved from the following scales: 'Equal Contribution' (Kramer et al., 1997), 'Discussion Quality' (Kramer et al., 1997), 'Dominance' (Kramer et al., 1997), 'Solidarity' (Wheeless et al., 1982), 'Affect' (Freeman, 1996), 'Fairness of Equal Scores' (Freeman, 1996), 'Fairness of Contribution' (Freeman, 1996), 'Waste of Time' (Freeman, 1996), 'Surplus Value of Group Work' (Freeman, 1996) together with some items that were constructed to indicate 'Illusion of Productivity', 'Free Riding', 'Downward Comparison' and 'Within Group Communication'. A few examples of questions are: 'I am satisfied with how group members interact with each other'; 'I feel we have good communication among group members'; 'I sympathize with my group'. All 57 items were scored on a common six-point scale (1 = strongly disagree; 6 = strongly agree) and subjected to a principal component analysis (Hair et al., 1995). Based on the 'eigen value > 1' criterion and inspection of the scree plot only one component was retrieved. A corresponding 'socio-emotive quality' scale was constructed by including all 30 items loading high (> |.40|) on the component. The scale's reliability coefficient was .82 (Cronbach's alpha (Hair et al., 1995)). Theoretical minimum, midpoint and maximum scores on this scale are 1; 3.5 and 6 respectively. A mean score of 4.47 (s.d. = 0.54) indicates that the subjects by and large were positive about the socio-emotive quality of the groups they were in. The SEQ-score for a whole team was defined as the mean of all team members' SEQ-scores.

Together with the SEQ-questionnaire all subjects were presented a short questionnaire with items describing learning goals with regard to social skills (eight items) and with regard to solving complex engineering problems (eight items). The exact wording of the items differed from year to year and in some project groups a few items were left out. Subjects were asked to indicate to what extent they agreed upon having reached the learning objective described (1 = strongly disagree; 6 = strongly agree). Examples of questions are: 'I've learned how to consult scientific sources' (learning about solving complex engineering problems) and 'I've learned to chair a meeting' (acquiring social skills). Scores for 'learning about engineering' and 'acquiring social skills' were computed by calculating the mean on all relevant items. Overall, means were 4.4 (s.d. = 0.9) and 4.2 (s.d. = 0.8) respectively. This observation is in line with the assumption that team work contributes to the mastery of complex engineering problems (assumption one) and to the acquisition of social skills (assumption two).

Finally students in the third project were asked to explicitly indicate on a 6 point scale to what extent they believe that learning results realised during both the first and the second project had helped them to solve engineering problems (4 items) and had helped them to acquire social skills (2 items) during the third project. Mean scores were 3.7 (s.d. = 0.9) and 4.1 (s.d. = 1.1) respectively. Students thus believe there is a learning transfer over projects.

5.2.6 Findings

To test the hypothesis that the SEQ of teams will improve trough the subsequent projects, an analysis of variance (ANOVA) with the teams' SEQ as the dependent variable and project as a three level between-subjects variable was performed (Hair et al., 1995; Moore and McCabe, 1997). The analysis revealed a 'project' main effect [$F(2,438) = 14.3$; $p < 0.001$]. The means of the socio-emotive quality of teams during the first, second and third project were 4.5; 4.4 and 4.6 respectively (see Figure 5-2). Contrary to hypothesis 1A, there is no unambiguous improvement of socio-emotive quality of teams over subsequent projects. In fact, a significant decrease was observed going from the first to the second project. Furthermore, and contrary to hypothesis 1B, the number of teams with a (very) low SEQ does not decrease over the subsequent projects. The lowest SEQ-values were observed during the third project.

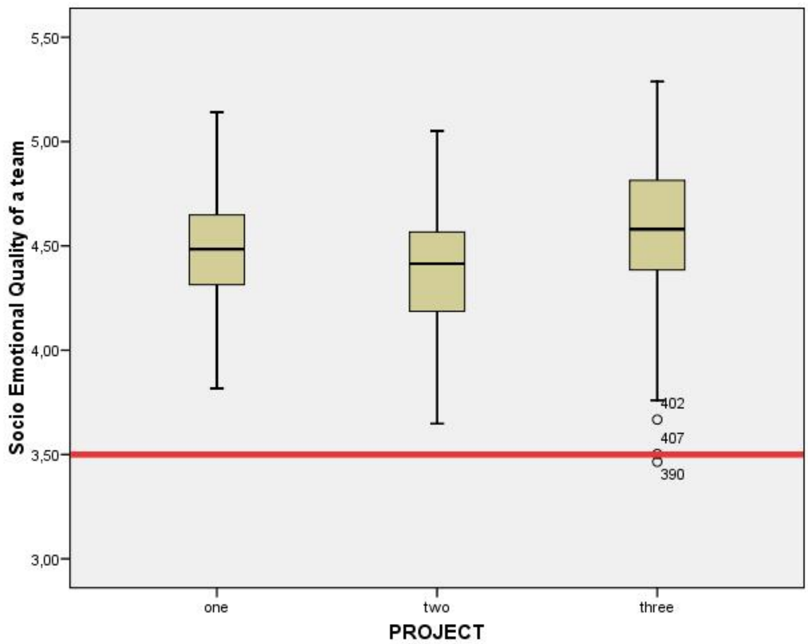

Figure 5-2. Box plot of the socio-emotive quality (SEQ) of teams during the first, second and third project. (A six-point scale was used with theoretical minimum, midpoint and maximum scores respectively 1; 3.5 and 6.)

In order to test hypotheses 2A, 2B and 2C a series of three multiple regressions (stepwise method) was performed (Hair et al., 1995; Moore and McCabe, 1997).

A first regression analysis aimed to predict the team SEQ-score at the end of the first project on the basis of their members scores for 'learning about how engineers solve complex problems' and 'acquiring social skills' at the end of the first project. The regression resulted in a model with a poor fit [($F_{1,1127} = 76.7$, $p < 0.0001$); $R^2_{adj} = 6$ %]. 'Acquiring social skills' was the only significant predictor ($\beta = 0.253$; $p < 0.001$). 'Learning about engineering' was not a significant predictor in this model.

A second regression analysis aimed to predict the team SEQ-score at the end of the second project on the basis of the following 5 predictors: perceived learning results about engineering during the first (1) and the second assignment (2); perceived success in acquiring social skills during the first (3) and the second (4) project; the SEQ-score that team members attributed to their first team (5). The regression resulted in a model containing two predictors and a poor fit [($F_{2,1063} = 50.8$, $p < 0.001$); $R^2_{adj} = 8{,}6$ %]. Perceived success in 'learning about engineering during the second assignment' ($\beta = 0.141$; $p < 0.001$) and perceived success in 'acquiring social skills during the second project' ($\beta = 0.184$; $p < 0.001$) both contribute to predict the team SEQ-score at the end of the second project. All other regressors were not significant.

A third regression analysis examines if and to what extent the SEQ of teams at the end of the third project could be predicted by one or more of the following ten predictors: perceived success in learning about engineering during the first (1), the second (2) and the third assignment (3); perceived success in acquiring social skills during the first (4), the second (5) and the third project (6); the SEQ-score attributed by team members to their first (7) and second (8) team; perceived learning transfer with regard to solving complex engineering problems (9); perceived learning transfer with regard to acquiring social skills (10). The regression resulted in a model containing two predictors and a poor fit [($F_{2,627} = 25.5$, $p < 0.001$); $R^2_{adj} = 7{,}2$ %]. Perceived success in 'learning about how engineers solve complex problems during the third project' ($\beta = 0.191$; $p < 0.001$) and perceived success in 'acquiring social skills during the third project' ($\beta = 0.123$; $p < 0.007$) both contribute to predict the team SEQ-score at the end of the third project. All other regressors were not significant.

All three regression analyses fit poorly, thereby indicating that the socio-emotive quality of a team is only (very) weakly determined by the predictors set forth in our hypotheses (2A, 2B and 2C). Overall the standardized beta coefficients of the significant predictor variables indicate only small effects on the criterion variable. Both the extent to which team members experience to acquire social skills as well as the extent to which team members experience to gain knowledge about solving complex engineering problems contribute (a little) to the social emotive quality of their team. However, contrary to what was hypothesized we were not able to trace any effect of these experiences on the socio-emotive quality of teams one will belong to afterwards. In the same line there seems to be no relation at all between the socio-emotive qualities of groups one subsequently belongs to. The SEQ-score that a team member attributes to his or her former team does not predict the team SEQ-score of the team he/she currently belongs to. All in all the results heavily contradict the basic assumption that re-assembling teams each semester (each project), allows students (from the second project on) to bring in and (re-)combine what they have learned and experienced during former projects. It thus seems as if the socio-emotive quality of a team of co-learners is (re-)assembled with unique 'team-specific parts' we currently don't know.

5.2.7 Discussion

By and large the pattern of results heavily contradicts our hypothesis. By re-allocating individuals to a new team at the beginning of each project we hoped to improve the SEQ of the new groups. It was hoped that students could start again with a clean slate and bring in their learning experiences from former groups (e.g. how to create trust in a group, good strategies to improve cooperative learning,…). The quality of groups did not improve over the three periods. The context of the group work changed over the three semesters (the projects are gradually formulated more openly and the students become more and more self-responsible for their teamwork). Because the group quality is not decreasing either, this could indicate that students gradually do learn to hold on to the same quality in increasingly complex contexts.

However there was not any trace found of transfer over periods. It thus nevertheless seems that the SEQ of a group is not so much a function of what people have learned during former interactions. Rather it might be an index of something that is easier sensed than rationalised. Within a newly formed group, members might quickly develop a sense whether or not they like each other. If the resulting SEQ is positive, then the group might benefit from it. However groups developing a defective SEQ might be at a disadvantage.

Given that the SEQ of a group is hard to control and/or to alter, future research should focus on how to successfully cope with such defective SEQ-groups. In the context of an educational setting one possibility might be to re-assemble only groups with a bad SEQ once more.

Given that the perception of making progress in the acquisition of social skills as well as being successful with regard to task related aspects of the assignment had a small but significant impact on the socio-emotive quality of the teams, one might not overlook the importance of designing challenging but achievable assignments and to provide opportunities to practice social skills. Moreover, on the assumption that the level of SEQ within a team of co-learners is determined very early on in their common history, it might be important to guarantee that a team experiences some (partial) successes right from the start.

Still another possibility might be to look and search for strategies that reside the impact of SEQ into the background. Perhaps, like in interpersonal relationships, groups that cannot reach an acceptable level of SEQ can opt for an (at least functional) marriage of convenience between its members?

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6 Conclusion and future perspectives

'Al onze vakken, heel theoretisch bekeken, zien we omgezet worden in praktijk. We zien de formules werken, we zien ze gebeuren voor onze eigen ogen.'

'All our courses, elaborated very theoretically, are transformed into practice. We can see the formulas work, we see them happening before our own eyes.'

(Mario Loncin, student P&O2 in 2006)

6.1 Context

Because of the increasing complexity of our ever changing knowledge society, present-day engineers need a wide set of technical and social competencies besides their solid base of scientific and technical knowledge (Bankel et al., 2003). They are required to solve complex open-end problems in various contexts, mostly in interdisciplinary teams. Therefore successful future engineers should possess at least two competencies (Denayer et al., 2003). They should be able to solve complex engineering problems and they should know how to work in a team. The ability to direct their own learning process and assess their performance, together with interpersonal and social skills are recognized as essential objectives in today's engineering education (Bary & Rees, 2006; Lemaitre et al., 2006; Lundberg et al., 2003).

Because of the Bologna Declaration of 1999, the Bachelor-Master structure was introduced in the higher education in Flanders. At the K.U.Leuven, the new programs in this BaMa structure were implemented year by year from 2004-2005 onwards. The Faculty of Engineering at Katholieke Universiteit Leuven, took this opportunity to introduce a new curriculum in September 2003. An integrated approach of science, technology and development of competencies from the first year onwards was chosen to make the engineering studies more relevant. Besides teaching a broad base of scientific knowledge and educating very specialized technological knowledge and skills, more attention goes to developing creativity, interdisciplinary problem-solving skills and communication skills. Therefore, a new course 'Problem Solving and Engineering Design' (P&O) was introduced, that takes a central position within all five years of the new engineering curriculum. From the first semester onwards a learning track is implemented to gradually build up engineering skills.

The P&O course of the first year has two main objectives: students need to integrate basic principles from the regular scientific courses to understand their connection and relevance and they need to acquire technical and social skills that are important within the engineering profession (like the ability to master new information independently; efficient use of ICT-tools; communication skills; a systematic approach to problem-solving and engineering design; simulation and experimentation skills; teamworking and project management skills; a creative and reflective spirit and critical attitude). Because of this variety of learning objectives, different teaching methods are integrated within the course. Learning objectives that are skills and not pure knowledge are not easily attained by classic lectures. Therefore the majority of the time the students work in teams on a project. The course ‘Problem Solving and Engineering Design’ is a student-centred course, based on the concepts of active and project based learning. The course implementation fits within the socio-constructivist approach of teaching and learning, where students learn together in small groups. More specifically the educational concept applied is cooperative learning. By means of project work, learning is centred around authentic and complex engineering problems and students learn how to collaborate in a team. Active learning methods that are student-centred and hands-on, are very suitable for introducing design concepts, a core business of the engineering profession.

The general hypothesis of this thesis was whether the particular implementation of project based learning that was developed and implemented in the course ‘Problem-Solving and Engineering Design’ in the first year of the bachelor of engineering at the K.U.Leuven results in attaining the objectives of course integration and gradual building-up of engineering competencies.

6.2 Conclusions

The course has two main groups of learning objectives. In the first place 'Problem Solving and Engineering Design' demonstrates the relevance and applicability of the basic principles taught in the regular scientific and technical courses. This should make the coursework more interesting and help the students master the abstract theories presented in lectures. The idea is that the students apply at least one basic theory of each regular course to complete the course project.

This part of the hypothesis can only be accepted partially. The students do recognise that they apply the basic principles taught in the regular courses to complete the team assignments. But fewer students are convinced to have learned more about these basic principles while working in team. This is reflected in the scores of the students on the individual test about the content of the projects. The mean scores are each year just around 50 %.

The second group of learning objectives of the course concerns technical and social skills. The students are gradually confronted with these goals:

- the ability to master new information independently;
- an efficient use of ICT-tools;
- communication skills: manual sketching techniques, object modelling using computer-aided-design software, writing technical reports and presenting their work orally;
- a systematic approach to problem-solving and engineering design;
- simulation and experimentation skills (simulation of the real world, design and set up of an experiment, data analysis, reflection and drawing of conclusions);
- teamworking and project management skills;
- 'engineering' attitudes: a creative and reflective spirit, critical attitude, accuracy, engagement and motivation.

This part of the hypothesis can also be accepted partially. The students do get gradually more skilled at these competencies, but the experience tells us that without a reminder from the didactic team, students often forget about their previous experiences and make the same mistakes again. Forcing the students to work with the feedback helps to make it an automatism and a real attitude.

More in detail the hypothesis was translated into three main research objectives:

1 Within this thesis the instructional format was designed and implemented by which the students can attain the predefined learning objectives. For designing the course format, the scheme of the general educational concept of the K.U.Leuven, Guided Independent Learning, was used as a starting point. The chosen implementation of the course 'Problem-Solving and Engineering Design' is a student-centred form of project based learning in which the students need to be active and work cooperatively in small groups.

First a generic framework for the instructional format of the course was designed to help the students attain these learning goals. Figure 6-1 gives an overview of the most important implementation characteristics of the course.

- *Student characteristics, learning objectives and context* are mostly predefined and therefore limiting conditions for the course. It is important to state the objectives clearly to the students, to encourage interaction of the project work with the other courses of the semester and to ensure a learning track over subsequent projects during the curriculum.
- *Learning activities:* In order to achieve the learning objectives, students need to be active and work on hands-on projects. They are encouraged to take initiative and become in that way more and more responsible for their own work.
- *Contents:* To motivate the students, the contents of the assignments is as authentic as possible, relates directly to the engineering profession and the daily life of the first year student.
- *Teaching methods:* Most of the time the students work in teams on multidisciplinary projects. The team sessions are supplemented by just in time engineering lectures to explain the application of technical skills. Peer feedback is implemented to enhance the students' critical attitude.
- *Materials:* Generic instructions are provided to the students within the course manual.
- *By whom:* To make the assignments as real and tangible as possible, experts are invited for the engineering lectures to motivate the students. The teamwork is facilitated by a tutor. It is important that the tutor has experience with the coaching teamwork and with the actual assignments. That way he or she can provide clear information about the objectives of the course, the expectations and the evaluation process.
- To support the students process guidance is important, as well as separately organised content- related guidance. The latter is not provided by giving ready-made answers but course specialists act as experts. The tutors provide feedback on the problem-solving process, the team functioning and the achieved products, thereby enhancing the students' critical attitude.
- The *evaluation* of the teamwork consists of a combination of group and individual assessments. Peer assessment is part of the evaluation process and is accompanied by extensive explanation and clear guidelines for the students.

Because of this generic framework (explained in chapter 2), it was possible to develop and implement two different sets of assignments for the project work within this thesis. Each set of assignments was situated within a challenging highly technological area that was related to the imagination of young engineering students and to their daily life by referring to the media as much as possible. Within the academic years 2003-2004, 2004-2005 and 2005-2006, the course was implemented around the technological theme aerospace engineering. This is an exciting highly technological theme that was in the media in Belgium around that time because of the flight of the Belgian astronaut Frank De Winne. In the academic year 2006-2007 a second set of assignments was drawn up within another technological theme 'energy'. Sustainability and careful energy consumption is a topic that is really hot at the moment and that inspires a lot of young students.

The generic framework made sure that every learning objective was accounted for and build-up in the course of the project work. Part of the instructions for the assignments could also be re-used because of their generic character. Changing the actual assignments is necessary because the students tend to pass on the solutions of their work. Moreover a new theme gives some fresh air and energy to the didactic team and to the students.

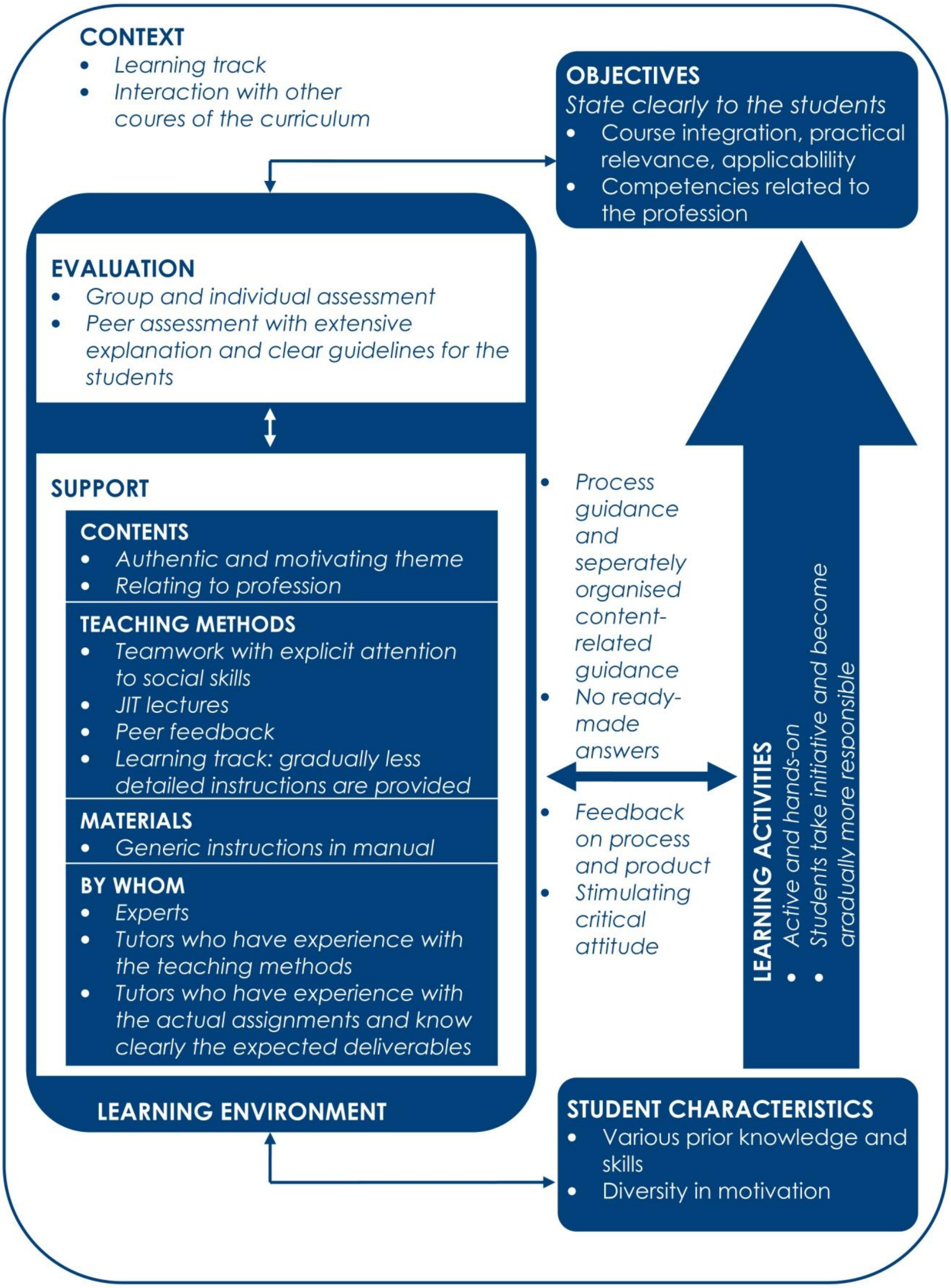

Figure 6-1. Summary of the implementation characteristics of the course 'Problem Solving and Engineering Design' in the first year of the Bachelor of Engineering. The italic items are the most important own contributions.

2 The second objective of this work was to organise student inquiries to evaluate and improve the course implementation. By means of this student feedback, together with the experiences of the staff involved, the course implementation could be evaluated to discover whether the course objectives were attained. Based upon the results the instructional format was optimised during the subsequent implementation years.

Chapter 4 describes the student feedback obtained by means of extensive questionnaires. Based upon this feedback, together with informal meetings with students and academic staff involved, the instructional format and the assignments were optimised during the subsequent academic years.

3 Particular aspects of the instructional format are analysed more in detail. Mainly the guidance of the students, the relationship between this guidance and the student learning goals and the socio-emotive quality of the students' teamwork will be evaluated. The questionnaires are composed by using multiple items (questions) measuring each topic. By using a factor analysis the actual components are computed based upon the data. The results are redirected to the implementation practice and recommendations for future improvements will be made.

In project work, a lot of attention goes to the *guidance of the students*. Literature defines a number of responsibilities for the tutor of a student team. In reality, often most of the time and effort goes to content-related guidance, because the students themselves urge continuously for content related help. The results of this study however reveal no correlation between the students' appreciation of this content-related guidance by their tutor and the perception of their learning. This might suggest separating even more clearly the content- and process-related guidance in future project work. In the current implementation, course specialists were already invited as experts. But it could be a possibility to make the daily tutors only responsible for providing information, guiding the problem-solving process and the team functioning, while the experts help the students with the scientific and technical content of the project assignment.

By re-allocating individuals to a new team at the beginning of each project we hoped to improve the *socio-emotive quality (SEQ)* of the new groups (the feeling they get on with each other). It was hoped that students could start again with a clean slate and bring in their learning experiences from former groups (e.g. how to create trust in a group, good strategies to improve cooperative learning, …). However, the quality of groups neither did improve over the three periods nor was there any trace of transfer over periods. It thus seems that the SEQ of a group is not so much a function of what people have learned during former interactions. Rather it might be an index of something that is easier sensed than rationalised. Within a newly formed group, members might quickly develop a sense whether or not they like each other. If the resulting SEQ is positive, then the group might benefit from it. However groups developing a defective SEQ might be at a disadvantage.

Given that the SEQ of a group is hard to control and/or to alter, future research should focus on how to successfully cope with such defective SEQ-groups. In the context of an educational setting one possibility might be to re-assemble only groups with a bad SEQ once more.

Given that the perception of making progress in the acquisition of social skills as well as being successful with regard to task related aspects of the assignment had a small but significant impact on the socio-emotive quality of the teams, one might not overlook the importance of designing challenging but achievable assignments and to provide opportunities to practice social skills. Moreover, on the assumption that the level of SEQ within a team of co-learners is determined very early on in their common history, it might be important to guarantee that a team experiences some (partial) successes right from the start.

Still another possibility might be to look and search for strategies that reside the impact of SEQ into the background. Perhaps, like in interpersonal relationships, groups that cannot reach an acceptable level of SEQ can opt for an (at least functional) marriage of convenience between its members?

6.3 Future perspectives

Course integration

The *relationship between the project work and the regular scientific and technical courses* can still be improved. During the lectures more reference can be made to the application of the basic theories within the technological theme of the project work. By involving the didactic teams of the regular courses in the development of the assignments the coherence and the uniformity can be guarded. In doing so the educational staff of the first year of the bachelor is confronted with all the basic scientific courses. Consequently, they realise that certain concepts and definitions appear in more courses (like energy, power, work done, differential equations, ...). This can be the incentive to explain the *coherence between the basic sciences* to the students. The professors can even make an effort to tune the use of the concepts more to one another.

It is important to *communicate the content and learning objectives of the course to the whole of the educational staff of the Faculty*. After all the students can build upon these experiences during the remainder of their educational life and the educational staff can make reference to and use of the basics and manuals used in the P&O courses of the first year.

The learning objective of course integration makes the coursework more interesting and demonstrates the applicability and relevance of the basic principles taught in the regular scientific courses. Moreover by integrating aspects of different courses to solve a problem, the students are confronted with the coherence of the basic sciences. The idea is that at least one basic theory of each first year course is integrated within the project work. Together with the learning objectives of engineering competencies, this is a precondition which has a great impact in defining proper assignments. However, although it requires a serious effort, the course integration objective should be guarded. This ensures that students look at the project work seriously and places the project in the centre of the curriculum. Moreover by emphasising the course integration and making it as explicit as possible, students can be encouraged to start studying for their regular courses. This is necessary, thinking of a recent study time measurement where a rather low study time was measured for most of the courses (for more details see appendix). Since the academic year 2008-2009 short home assignments were implemented within the P&O course. Every home assignment was aimed at studying a basic principle from a regular course that was needed to solve the project assignment the week after. In a team of eight students, eight different home assignments were defined. That way the students are encouraged to start working on their regular courses and to prepare the team assignments more carefully.

Improvements of the course implementation

It is important to make the project work *as hands-on as possible*. Certainly in the first semester a hands-on experience to relate the theory with a practical application motivates the students. Since the academic year 2008-2009 a small design assignment was included at the end of the first semester. The teams are asked to design, build, test and demonstrate a small car that runs down a hill towards a wall. The assignment is to ride as fast as possible as close as possible to the wall (but the car may not touch the wall). This addresses the creativity of the students and provides a hands-on experience. A team of eight students works 8 hours (or two team sessions) on this design assignment. In the future it would be a good idea to plan a practical oriented assignment more early in the semester. Because most of the students like the big assignment of the second semester, it could even be a good idea to *make the smaller assignments of the first semester more coherent* and relate them all more clearly to one product. It is however necessary to keep the assignments themselves relatively small en clearly distinctive with clearly stated deliverables and deadlines because the first year students have no experience yet in planning a big assignment and dividing their team into subteams.

To make sure that *each student is directly involved in the teamwork, and feels responsible* for the outcome of his team, in the beginning of the semester smaller (sub)teams can be formed. For example the semester can start with two subteams of four students (or even four subteams of 2 students). By assigning different subtasks to each small team, they can share results when the semester progresses and the two subteams make one big team of eight students.

Another idea is to *abandon the principle that all work needs to be done in the design room* within the scheduled time. By stating clear minimum deliverables that the teams need to finish (possibly at home), they are more forced to work and feel responsible for the outcome of their teamwork.

Since the academic year 2008-2009, *peer feedback* is implemented in the project work of the second semester. Halfway the semester each team hands in a written report of their design concept. By means of an online journal system, the reports are distributed among all students and every student makes a review on the content and the writing style of one of the concept reports. That way the teams get eight peer-reviews to improve their written report. In the present academic year 2009-2010 the students evaluated the presentations given by their colleagues at the end of the second semester. Both experiences were positive and useful feedback is given by the students. Therefore in the future a similar form of peer feedback can be incorporated in the assignments of the first semester. A possibility is to organise a small design competition by asking the students to evaluate and rate the design products of the other teams.

Guidance of the teamwork

Because of the relatively low number of educational staff, the challenge is to find a balance in the guidance of the project work by *putting the most effort in the most effective tutor responsibilities* (answering content-related questions, guiding the problem solving process, providing information about the objectives and deliverables, giving feedback and assessment). More research is needed for defining the right time use of the tutors and the effect on the learning experience and learning efficiency of the students. Probably this depends also, at least partially, on the nature of the tutor and his or hers guiding style (more or less directive for example). Also a more *objective measurement of the learning outcome* of the students is needed. This is a challenge because it is not easy to measure objectively a student's ability and progress in mastering social competencies, moreover because of the limiting amount of educational staff available for all the coaching and assessment.

However, based on the research done within this thesis, future changes can be made with respect to the guidance of the teamwork by making a *clear distinction* *between the tutor of a team and the course specialists*. The tutor explains the objectives of the course, the deadlines and deliverables; he or she coaches the team with respect of the problem solving process and the teamwork and gives feedback. Fixed meetings with the tutor, instead of a constant coaching during the whole team session, can guarantee a more consequent and steady monitoring of the teams' progress during the semester. This also encourages the students to feel more responsible for their project and to work more independently. The instructions, the P&O manual, the electronic learning environment and the (mini) library contain information about the problem solving process and the contents of the assignments to help the students solve the problems. When needed, short just in time lectures, can provide background information about a particular skill (how do I write a good scientific report?) or about the content of the project (which sensors are used during the experiment and how do they work?). The course specialists are experts and the students can ask them concrete questions about the content of the assignments, related to the application of the basic principles taught in the regular courses. It is important that the educational staff do not provide readymade answers, but instead coaches the problem solving process and helps the students to look for the information they need.

Socio-emotive quality of a student team

Given that the socio-emotive quality (SEQ) of a group is hard to control and/or to alter, future research should focus on how to successfully cope with defective SEQ-groups. In the context of an educational setting one possibility might be to re-assemble only groups with a bad SEQ once more.

Given that the perception of making progress in the acquisition of social skills as well as being successful with regard to task related aspects of the assignment had a small but significant impact on the socio-emotive quality of the teams, one might not overlook the importance of designing challenging but achievable assignments and to provide opportunities to practice social skills. Moreover, on the assumption that the level of SEQ within a team of co-learners is determined very early on in their common history, it might be important to guarantee that a team experiences some (partial) successes right from the start.

Still another possibility might be to look and search for strategies that reside the impact of SEQ into the background. Perhaps there can be opted for shorter team existence with a dominant focus on the tasks at hand? This seems a bit in contradiction with the (subjective) feeling of the students who like the design project of the second semester the most. However some students do acknowledge that the clear instructions of the first semester makes it more easy to organise their team functioning.

More research can also be done on the team formation itself: is the SEQ of a team dependent on the personalities of the students of a team? And is it possible to make an ideal team formation (Peeters-Baars, 2006)?

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7 Appendices

7.1 Evaluation of the implementation characteristics

7.1.1 *Introduction*

For evaluating the course implementation feedback was obtained from students and staff involved.

For four subsequent academic years, all first year students enrolled in the course 'Problem Solving and Engineering Design' completed an extensive questionnaire at the end of each semester. In this way feedback was obtained from the students, which offered opportunities to improve the implementation of the course concept. Additionally at the end of each academic year interviews were organised with a few students volunteering. That way the answers from the questionnaires could be verified and possible changes in the course organisation could be discussed.

Table 7-1. All students enrolled in a 'Problem Solving and Engineering'-course filled out a questionnaire. This table gives an overview of the course abbreviations that will be used in the histograms to present the results and the number of students who completed the questionnaires.

Academic year	Technological theme	P&O1 Semester 1 (= *moment 1*)	P&O2 Semester 2 (= *moment 2*)	P&O3 Semester 3 (in the next academic year) (= *moment 3*)
2003-2004 (=*1*)	Aerospace engineering	383	408	272
2004-2005 (=2)	Aerospace engineering	388	378	308
2005-2006 (=3)	Aerospace engineering	381	363	276
2006-2007 (=4)	Energy	383	328	/

Table 7-1 gives an overview of the available data and explains the abbreviations that will be used in the histograms to present the results. Each semester, all 300 to 400 students enrolled in the 'Problem Solving and Engineering Design'-course, filled out the questionnaire. Students were asked to indicate to what extent they agreed upon the statements (1 = strongly disagree; 6 = strongly agree). Only in one occasion, a maximum of 6 % blank answers were counted for the questionnaire in the first semester of the academic year 2005-2006 on a statement for one particular questionnaire. When including all data, the maximum amount of blank answers on a statement is 2 %.

This section gives a more detailed overview of the data from the questionnaires. The questions are interpreted one by one because this gives useful feedback to optimise the implementation characteristics of the course.

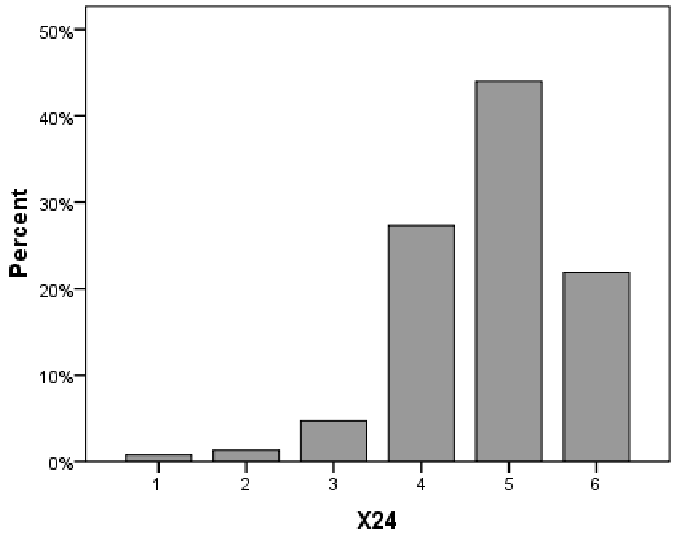
- The questions are reported with the exact wording (translated from Dutch into English).
- Overall mean values were calculated based upon the whole dataset.
- The percentages of students that agreed upon the statements were calculated by taken into account the scores 4, 5 and 6 (rather agree, agree and strongly agree) (Lundberg et al., 2003).
- Histograms are shown using the percentage of answers provided by the students and show the original question-numbers.
- For every statement a one or two way ANOVA was performed, with the agreement on the statement as dependent variable and the semester and/or academic year as independent variable(s) (without taking into account the interaction between the two factors semester and academic year). Significant difference was defined between the mean values when $p < 0,05$. When significant differences occur, means plots with 95 % confidence intervals are added.

7.1.2 Concept of P&O

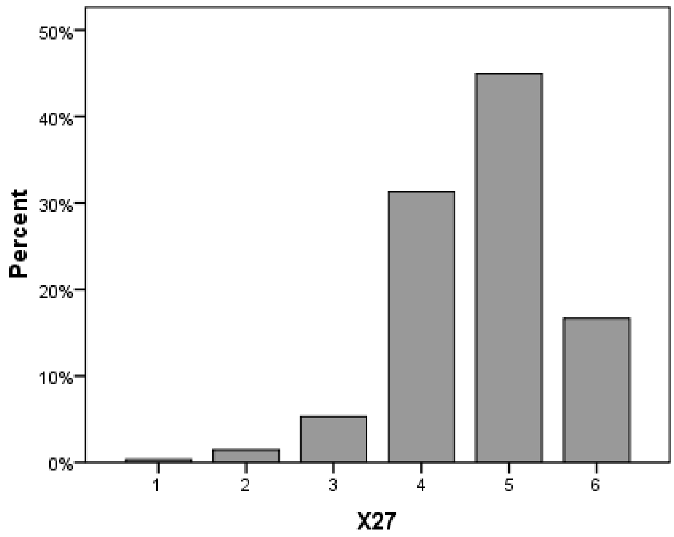
‘Problem Solving and Engineering Design’ was introduced to make the engineering studies more relevant from the first semester onwards. The students respond enthusiastically. The histograms of Question 7-1 and Question 7-2 show that they clearly see the added value of this new course for their engineering study and feel teamwork is an enriching experience.

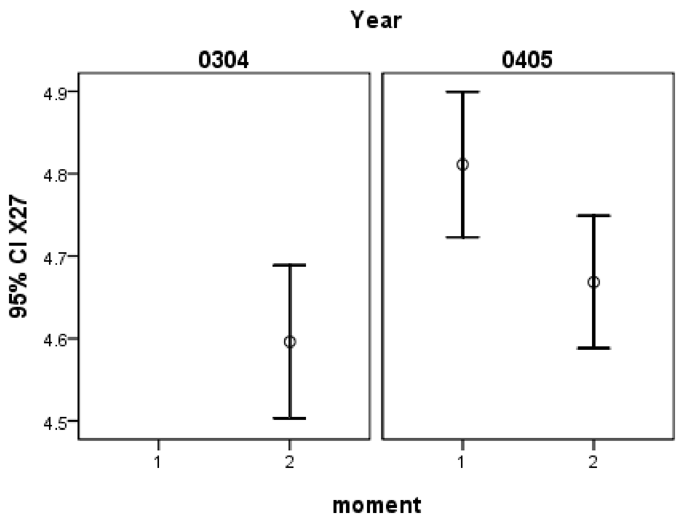
Moreover 93 % of the students feel that the course objectives are realistic in the first year of their study (Question 7-3).

Question 7-1. I clearly see the relevance of the course for my engineering study.
Overall mean: 4,78 (s.d. = 0,94; n = 1879).

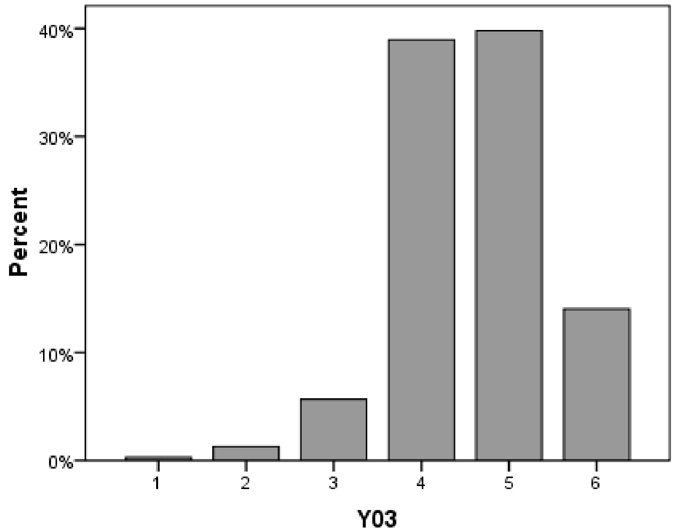


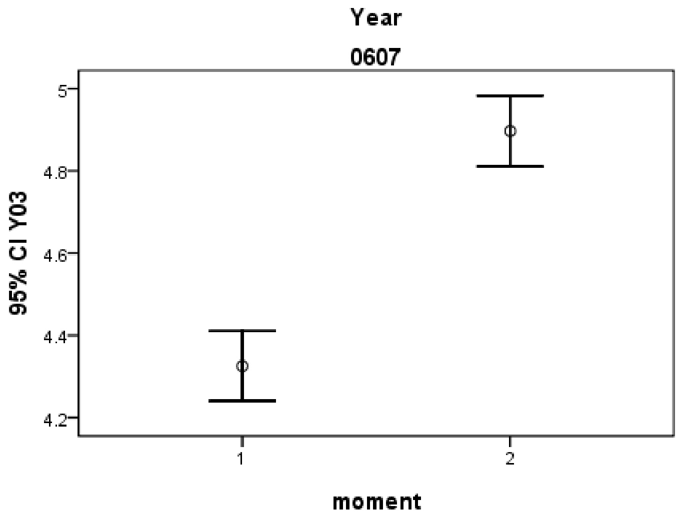
Question 7-2. Teamwork is an enriching experience. *Overall mean 0,69 (s.d. = 0,88, n = 1170). In the academic year 2004-2005 (year 2) there is a significant difference between the means of the two semesters: the result for P&O1 is significantly higher. For the second semester, there is no significant difference between the academic years 2003-2004 and 2004-2005.*





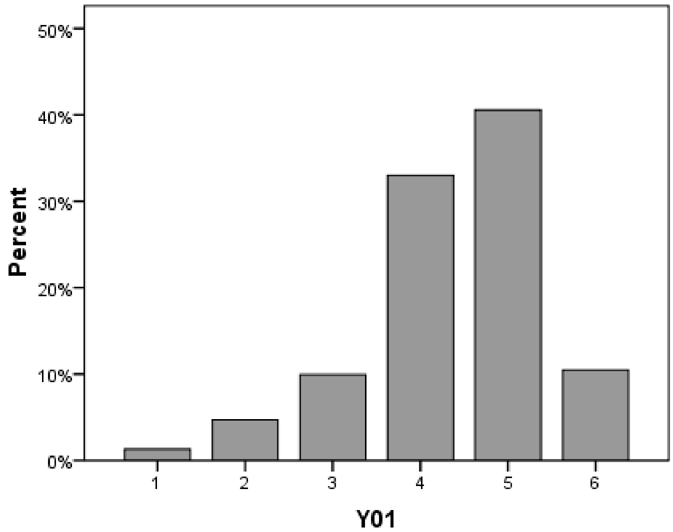
Question 7-3. <u>The course objectives are realistic at this point in my study.</u> *Overall mean 4,59 (s.d. = 0,86; n = 706). This statement was only included in the academic year 2006-2007. The value for the first semester (4,33; s.d. = 0,86; n = 381) is significantly lower than the mean of the second semester (4,90; s.d. = 0,78; n = 321).*



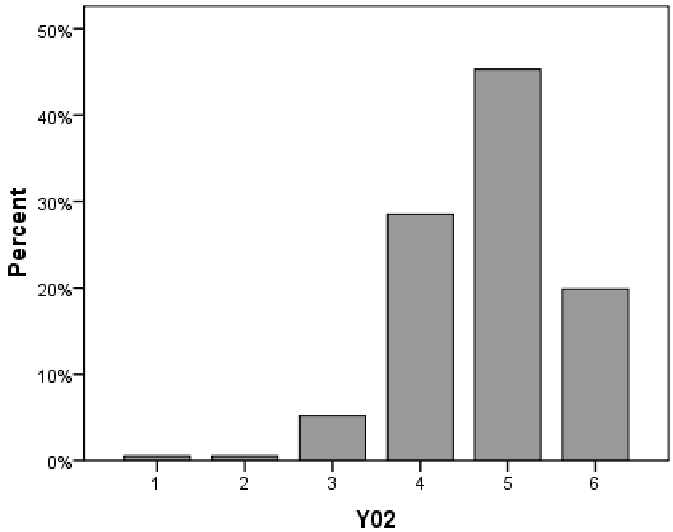


The majority of the first year students are interested in the relationship between theoretical principles and the engineering practice. The students believe that the project based course contributes to the understanding about the application of the theory (Question 7-4, Question 7-5 and Question 7-6).

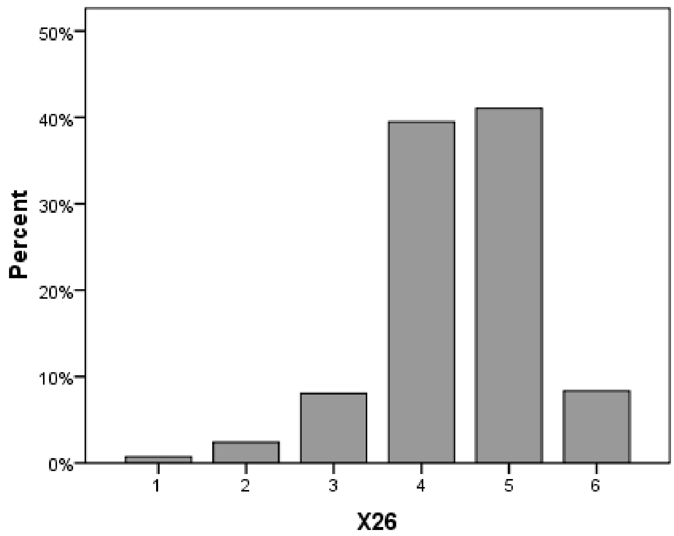
Question 7-4. Its relevance for my future profession makes this course fascinating. *Mean 4,38 (s.d. = 1,04; n = 382). This statement was only part of the questionnaire of the first semester in the academic year 2006-2007. 84 % of the students agreed upon this statement.*



Question 7-5. I am interested in the connection of theory and practice. *Mean 4,77 (s.d. = 0,88; n = 382). This statement was only part of the questionnaire of the first semester in the academic year 2006-2007. 94 % of the first year engineering students agreed with this statement.*



Question 7-6. The way the teamwork is organised, helps me to understand the connection between theory and practice. Mean: 4,43 (s.d. = 0,90; n = 709). This statement was part of the questionnaires of the first and second semester of the academic year 2006-2007.

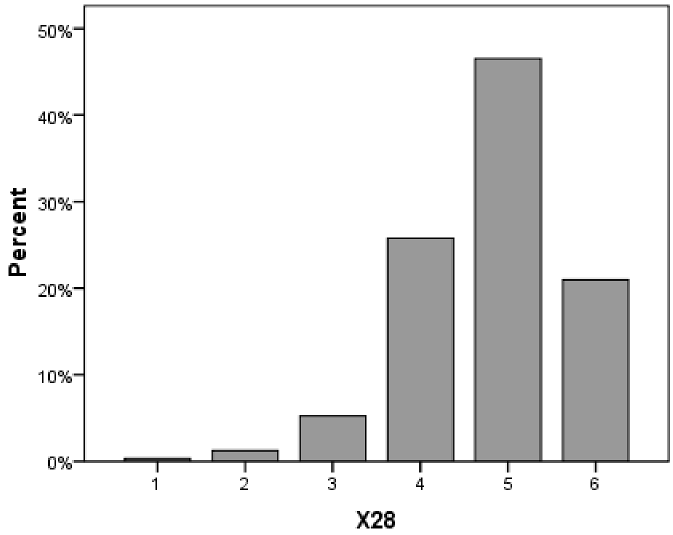


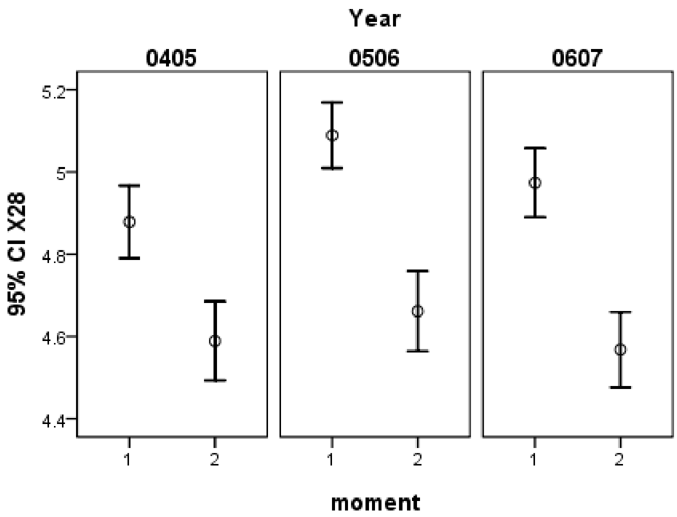
7.1.3 Technical competencies

7.1.3.1 Course integration

One of the main objectives of 'Problem Solving and Engineering Design' is to demonstrate the relevance and applicability of the basic principles taught in the regular scientific and technical courses. The integration of all courses however remains a challenge. The histogram shows that although the majority of the students clearly see that they need to integrate different courses to complete the team assignment (Question 7-7), fewer students are convinced that they have learned more about these basic principles while working in team (Question 7-8).

Question 7-7. <u>I integrated basic principles of different regular courses to complete the team assignment</u>. *Overall mean 4,80 (s.d. = 0,89; n = 2194). A two way ANOVA shows a significant effect of the semester. The average for P&O1 (= moment 1) is significantly higher. There is no significant effect of the academic year.*

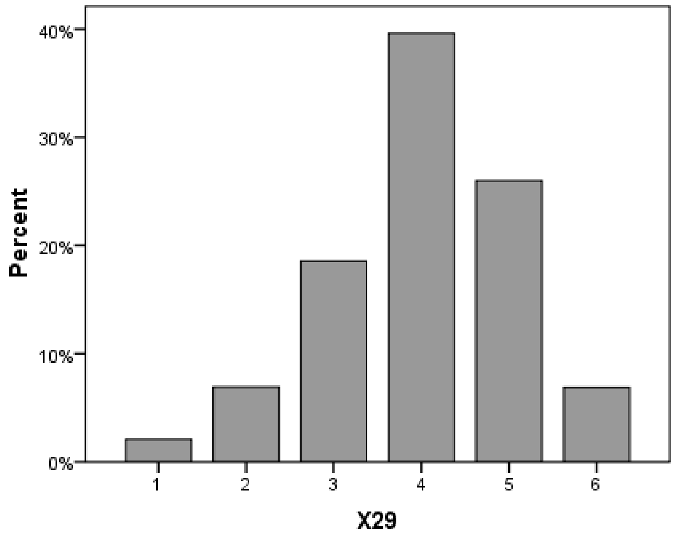


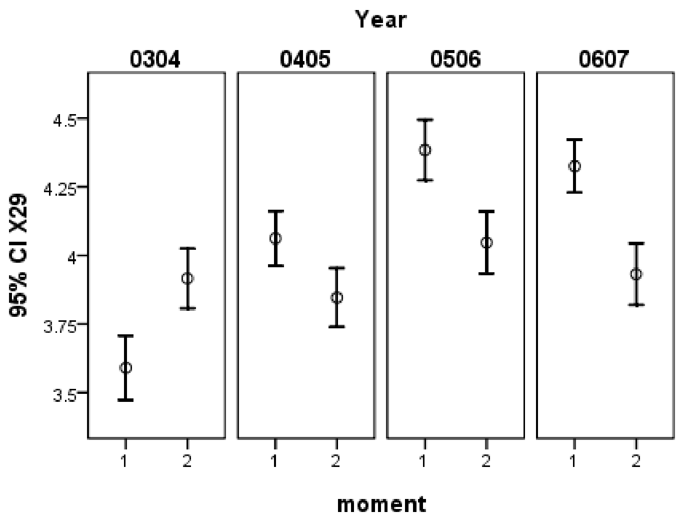


Question 7-8. <u>Through the teamwork I understand better the basic principles taught in the regular scientific courses.</u> *Overall mean 4,01 (s.d. = 1,09; n = 2980).*

There is a significant effect of the semester: in the first implementation year, 2003-2004, the average score for P&O2 was significantly higher. For the following three years, the score for P&O1 was significantly higher. This reflects the effort that was put in to improve the course integration. Especially in the project of the first semester the assignments now clearly indicate the basic theories that are necessary to solve the problem. This encourages the students to study the theories of the basic scientific courses that will be applied in the project.

Looking at P&O1 only, the average result in the academic year 2003-2004 is significantly lower than the average result in 2004-2005, that is significantly lower than 2005-2006 and 2006-2007. For P&O2 there is no significant difference between the means of subsequent academic years.





Based upon the results of the first implementation year, the integration of the team assignments with the individual courses has constantly improved. Several measures were taken to make students more aware of the importance of understanding the basic principles: the link with the regular coursework is clearly indicated in the project assignment – especially in the first project-, all teams are forced to include short abstracts in their team portfolio to explain the basic theories they apply to solve the assignments and at the end of the course each student has an individual test on the applied principles. Especially in the first semester a lot of attention goes to the application of basic theories of the regular courses. This is reflected in the histograms.

At the end of each semester, all students take an individual test about the content of the project work. That way the important objective of course integration and the application of basic scientific theories can be evaluated individually. The test is an open book examination where the students are asked to apply the same principles they used during the teamwork to solve similar problems. The mean scores on this written test also reflect the difficulties that the students experience when they need to apply basic principles from the other courses (Table 7-2). This may be the reflection of the actual passing rate of the students at the end of the first year.

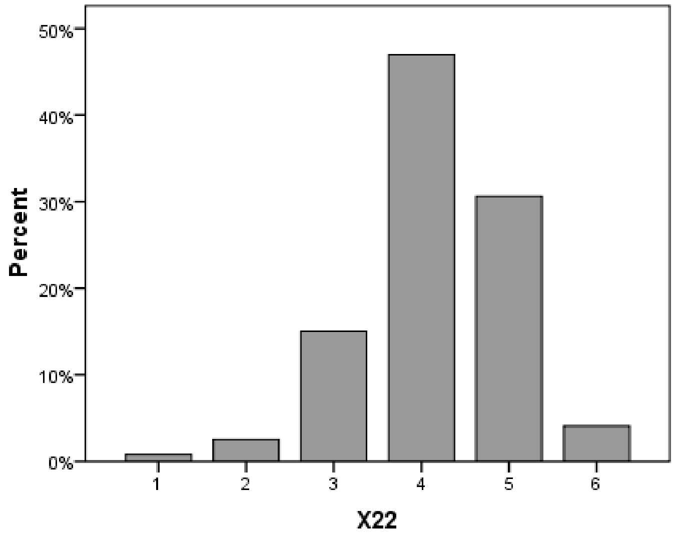
Table 7-2. Mean scores (on 20) on the written individual test at the end of a project.

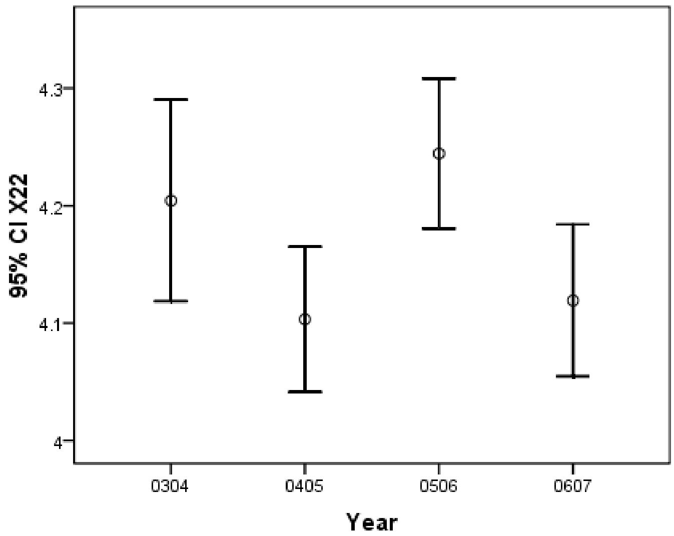
Academic year	**1st semester (P&O1)**	**2nd semester (P&O2)**
2003-2004	(no test organised)	9,8 (s.d. = 3,6)
2004-2005	11,3 (s.d. = 4,5)	10,5 (s.d. = 3,2)
2005-2006	8,4 (s.d. = 3,6)	9,7 (s.d. = 3,4)
2006-2007	11,9 (s.d. = 4,4)	9,1 (s.d. = 3,1)

7.1.3.2 Information skills

Besides applying theories from the regular courses, students also need to master new information about the subject and technological theme of the project, about the numerical calculation in Maple, ... The data from the questionnaires shows that the majority of the students believe to have learned to master new information independently (Question 7-9). There is no significant effect of the semester, but the average result for 2005-2006 is significantly the highest. This was the third implementation year for the aerospace engineering projects and all assignments are optimized.

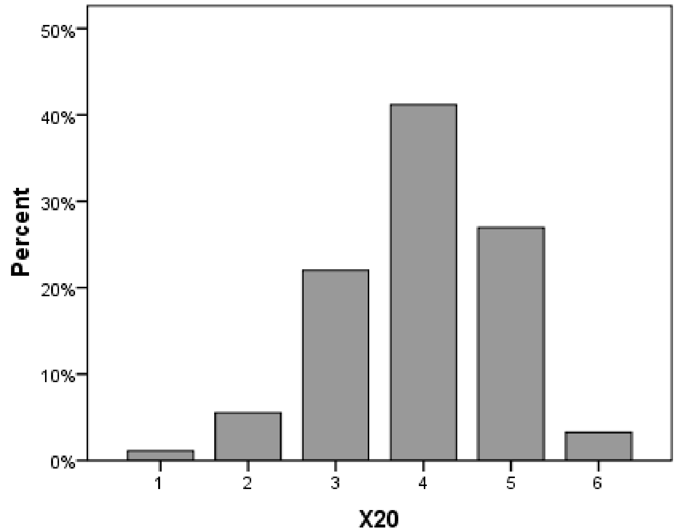
Question 7-9. Through the teamwork I learned how to master new information independently. *Overall mean 4,16 (s.d. = 0,88; n = 2599). There is a significant effect from the academic year. The average of the academic year 2005-2006 is significantly higher than 2006-2007 and 2004-2005.*

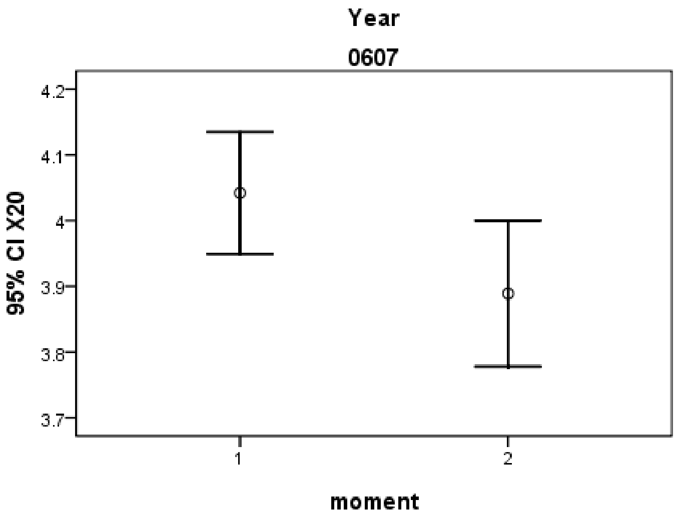




In the first semester the assignments indicate more clearly when students should look for additional information and how it should be used. In the second semester students work more independently. However not all students believe they have learned how to refer to relevant sources (Question 7-10), the overall mean is 3,97; which is below 4 (rather agree). There is however a significant effect of the semester: the average result for the first semester is significantly higher.

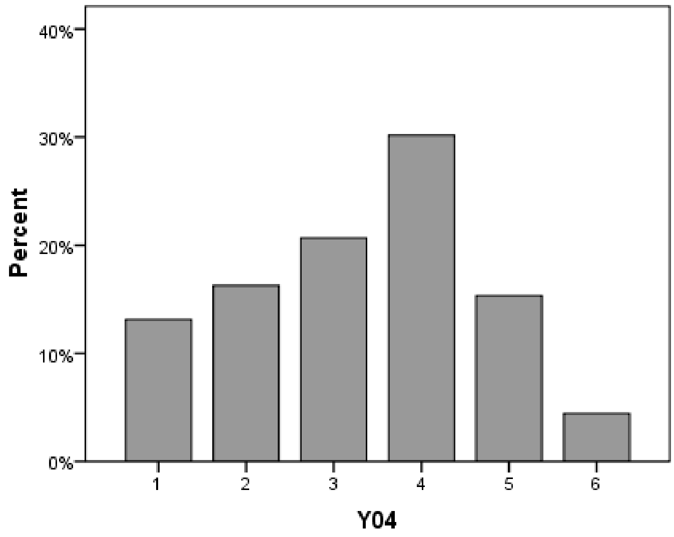
Question 7-10. Through this course I learned how to refer to relevant sources. *Overall mean 3,97 (s.d. = 0,97; n = 709). This statement was only included in the questionnaire of the academic year 2006-2007. There is a main effect from the semester: the mean of P&O1 (4,04; s.d. = 0,92; n = 381) is significantly higher than for P&O2 (3,89; s.d. = 1,01; n = 324). This can be explained by the amount of time students put in their literature study at the beginning of the first semester. In the whole of the first semester more attention goes to external information sources that way that they are more clearly indicated by the didactic team.*





Part of the introduction into information competencies takes place during a guided tour in the library in the beginning of the academic year. Despite a literature assignment for which they immediately need to start searching for information, the overall mean on Question 7-11, whether the guided tour is useful, is only 3,32; which is less than 3,50 (not disagree, not agree).

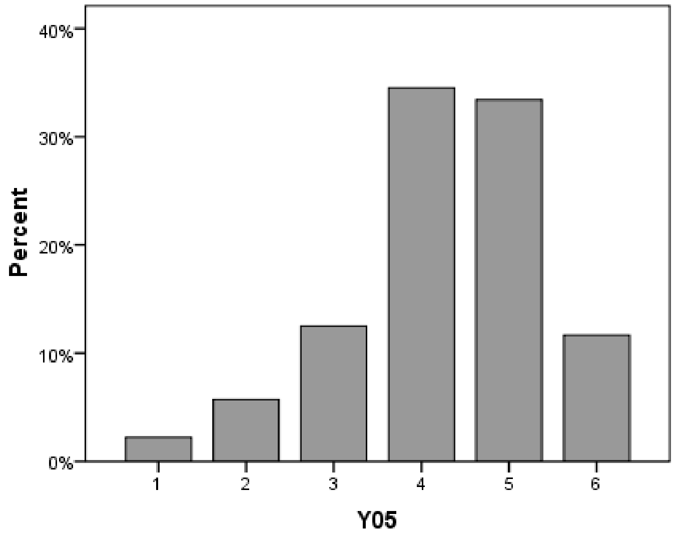
Question 7-11. The guided tour in the library was useful to me*. Overall mean 3,32 (s.d. = 1,38; n = 769). The guided tour takes place in the beginning of the academic year so this statement was only included at the end of the first semester in the academic years 2004-2005 and 2006-2007. There was no significant effect of the academic year. 50 % of the interrogated students agreed the guided tour to be useful. Not all students find the tour useful, because they do not see the immediate use and do not make the direct connection with their grades.*



7.1.3.3 Modelling and experimenting

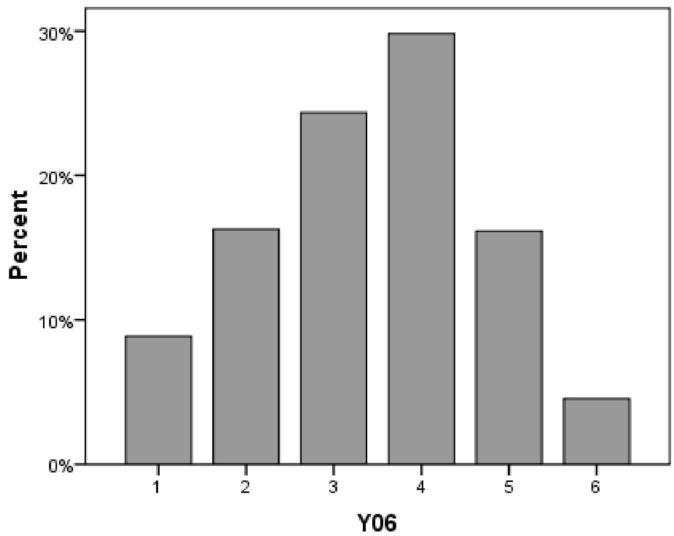
In the second semester students learn how to model objects and processes by using Computer Aided Design software (Solid Edge) and Finite Element Models. These competencies are useful while working on a design project. 80 % of the students agreed to have used these skills while working on the project of the second semester (Question 7-12).

Question 7-12. What I learned during the instruction lecture and exercises about the modelling objects and processes (with CAD and FSM), helped to complete the team project with a good result. *Overall mean 4,26 (s.d. = 1,13; n = 2242). This concerns only P&O2. There is no significant effect from the academic year.*



To introduce the first year students into scientific experimenting a lot of attention goes to the setup, the protocol, the measuring and data processing. In the first semester all teams perform an experiment about combustion and propulsion. This is accompanied by a lecture about safety. Although the lecture was combined with the assignment to draw up a risk analysis of the performed experiment, only the half of the students (51 %) is convinced of its usefulness (Question 7-13).

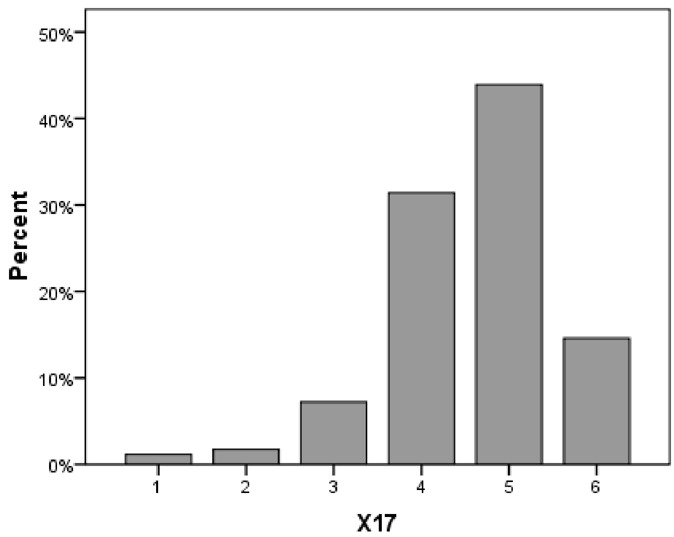
Question 7-13. The lecture about safety was useful. *Overall mean 3,42 (s.d. = 1,30; n = 768). Also for this lecture students do not see the immediate connection with their grades, so they find it less interesting.*

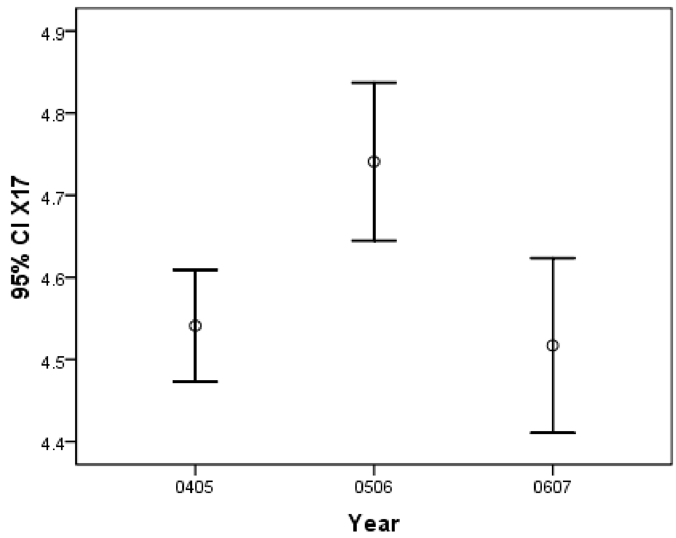


In the second semester the design project entails an experiment to measure the characteristics of the designed object and at the end all teams also demonstrate their design in a small competition. During the demonstration different parameters are measured to evaluate their calculations.

The majority of the students believe these experiments make a useful introduction (Question 7-14). According to the exact assignment they worked on, they are more convinced. In the academic year 2005-2006 more attention was paid to this competency. A list of small deeper questions was added to the assignments and students were more encouraged to analyse the data critically. In the second semester of that same year the students experimented a lot more, because a bigger part of the design was solved using trial and error methods. It was the third year of the aerospace engineering theme and the assignment for the second semester consisted of the vertical launching of a water rocket with an un-boiled egg as payload. For completing this design, all students experimented a lot more in comparison with the two previous years. Extra launching trials were put in the schedule and each team session the team could test their parachutes by throwing them out of the window at the fourth floor of the building.

Question 7-14. The experiment we performed while working in team was a good introduction into scientific experiments. *Overall mean 4,59 (s.d. = 0,96; n = 1455). There is a significant effect of the academic year. The mean for 2005-2006 (4,74; s.d. = 0,93; n = 363) was significantly higher than 2004-2005 (4,54; s.d. = 0,96; n = 765) and 2006-2007 (4,52; s.d. = 0,97; n = 323). 2005-2006 was the third year of the aerospace engineering theme and the assignment for the second semester consisted of launching the water rocket vertically with an un-boiled egg as payload. For completing this design, all students experimented a lot more in comparison with the two previous years. Extra launching trials were put in the schedule and each team session the team could test their parachutes by throwing them out of the window at the fourth floor of the building.*

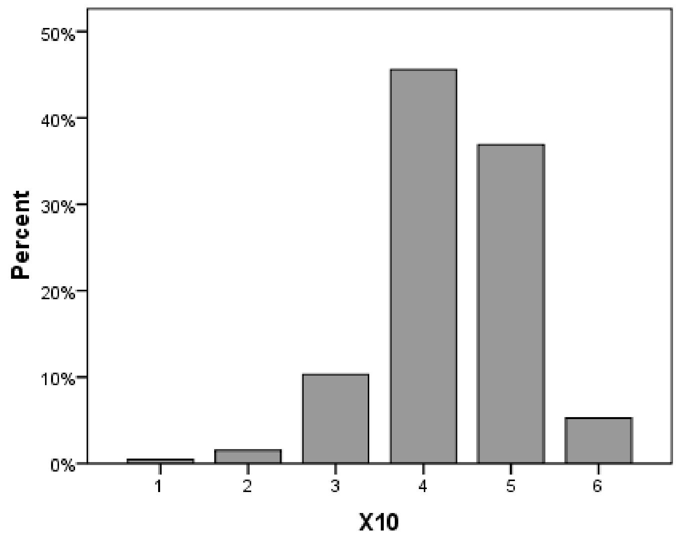




7.1.3.4 Systematic problem-solving

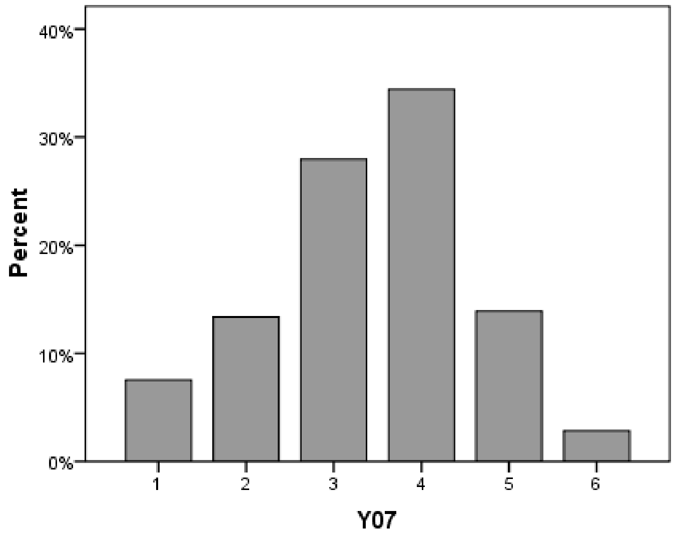
One of the objectives of the course is to teach the students a systematic way to approach problems. The seven step procedure (TSM - Teaching & Schoolmanagement consultants, 2010) is used as a tool and written documents help the students to overcome problems they encounter in a systematic way. 88 % of the students believe to have learned a systematic approach to solve problems (Question 7-15).

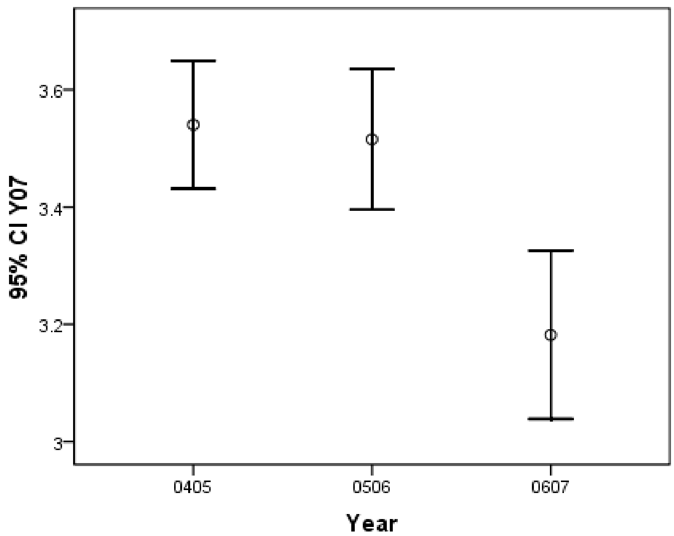
Question 7-15. Through the group project, I learned to use a systematic approach to solve problems. Overall mean 4,33 (s.d. = 0,82; n = 1505).



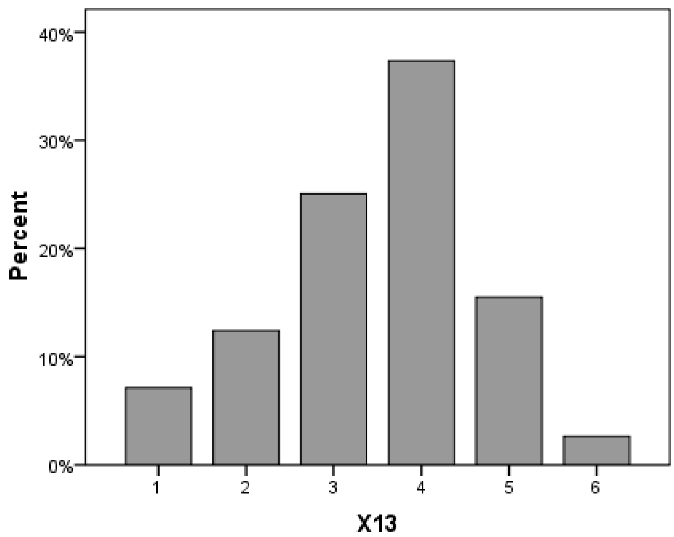
In the second semester students also get to know a systematic way to designing and plan their project. Although all teams are forced to use the lectured methods during their project, students do not really belief they benefit from these lectures (Question 7-16 and Question 7-17).

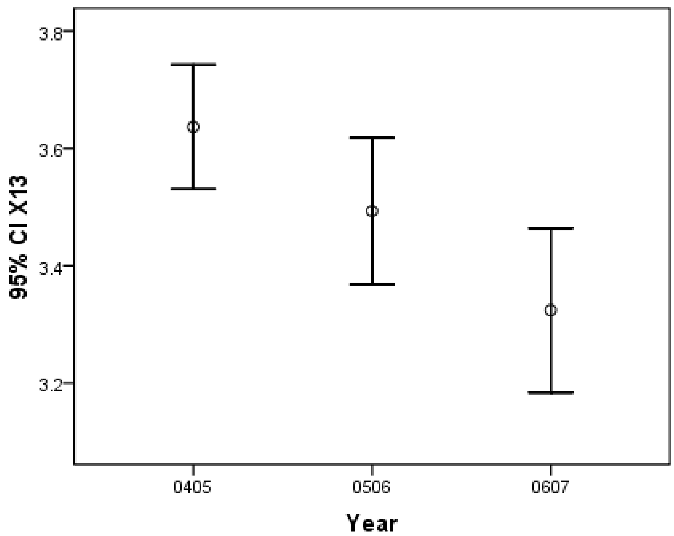
Question 7-16. [What I learned during the introductory lecture about the design process, helped to complete the team project with a good result.] *Overall mean 3,42 (s.d. = 1,19; n = 1063). This lecture takes place in the second semester, so all data is from the questionnaire at the end of the second project. The average value for the academic year 2006-2007 (3,18; s.d. = 1,13; n = 324) was significantly lower than the others (3,51 (s.d. = 1,16; n = 361) in the academic year 2005-2006 and 3,54 (s.d. = 1,07; n = 374) in 2004-2005).*





Question 7-17. <u>What I learned during the introductory lecture about the project planning, helped to complete the team project with a good result.</u> *Overall mean: 3,50 (s.d. = 1,18; n = 1066). This lecture takes place in the second semester, so all data is from the questionnaire at the end of the second project. The score for the academic year 2004-2005 (3,64; s.d. = 1,05; n = 377) was significantly higher than for 2006-2007 (3,32; s.d. = 1,28; n = 324).*



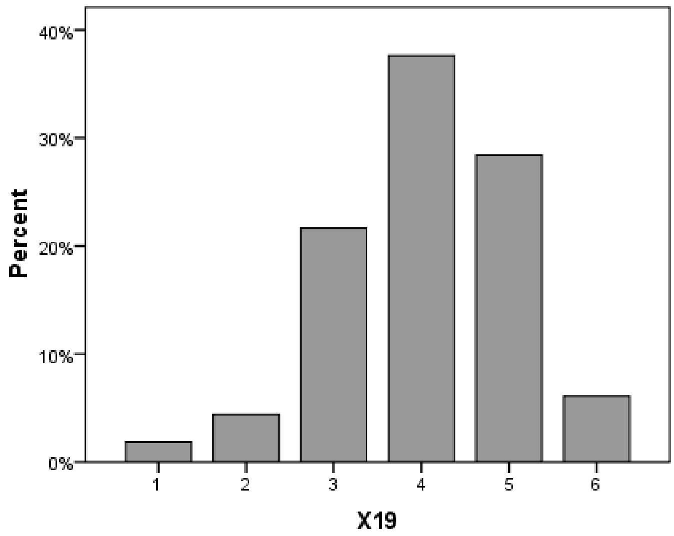


These ratings are rather low. The lecture about project planning and systematic designing always seems very theoretical to the students. They do not see how this lecture can be useful to their project. After introducing small examples in the lectures, in the academic year 2008-2009 a young engineer was invited to clarify the connection between the theory and his every day practice. Students reacted more interested and looked at the engineer like he was 'one of them'.

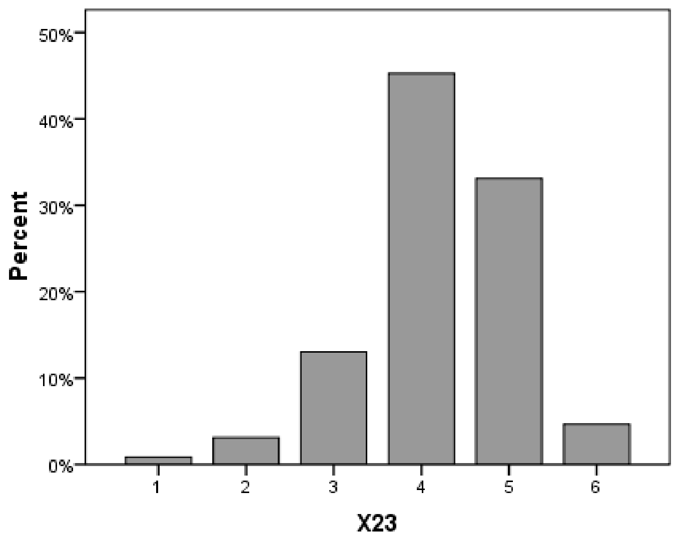
7.1.3.5 Attitudes

One of the objectives of the course is to teach the students to work more independently and think critically to evaluate their work. Measures were taken to force the students to reflect upon their activities: each student fills out an individual logbook and self-assessment is a part of the peer assessment procedure. However this can still be improved (Question 7-18 and Question 7-19).

Question 7-18. Through the teamwork I learned to work more independently. *Overall mean 4,05 (s.d. = 1, 04; n = 707). This question was only part of the questionnaire in the academic year 2006-2007. There was no significant effect of the semester.*



Question 7-19. During the team project I reflected upon my activities to check whether I could improve on something. *Overall mean: 4,21 (s.d. = 0,90; n = 707). This question was only part of the questionnaire in the academic year 2006-2007. There was no significant effect of the semester.*



7.1.4 Social skills

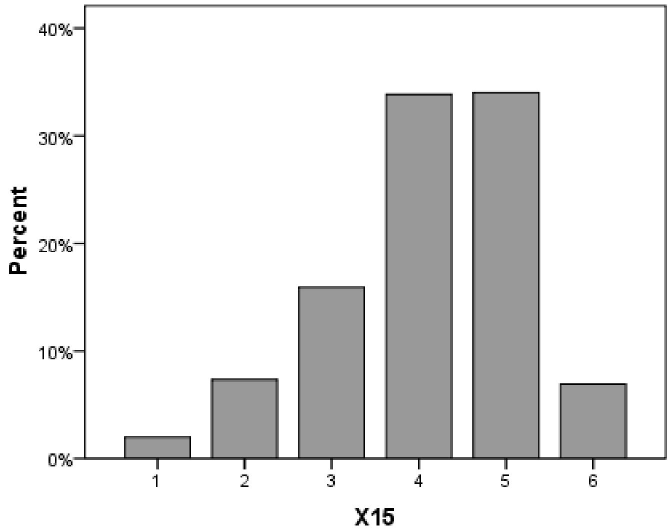
7.1.4.1 Communication skills

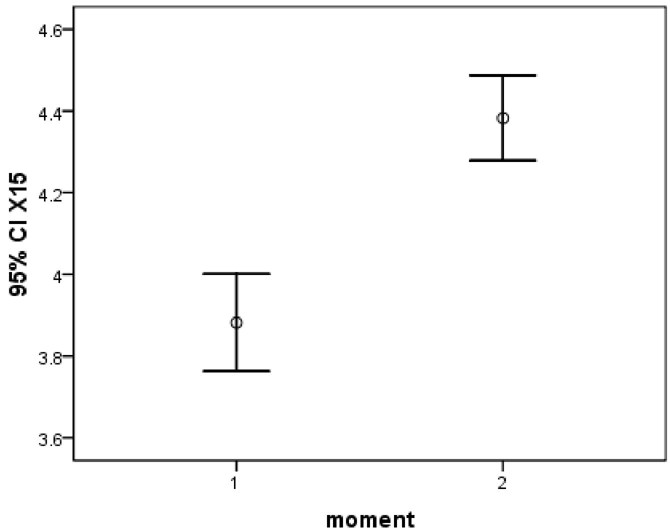
Oral and written communication is an important part of the course. In the first semester students mainly work on written technical reports, on which they get extensive feedback. At the end of the second semester each team hands in a written report of their design project and gives an oral presentation. Because of practical reasons the questionnaires were filled out before all students gave their oral presentations, so there is no real student data about oral communication.

It is the experience of the didactic team that the students find it hard to write a good scientific report. In spite of repeated feedback and reminding the students of their previous errors, they still make often the same mistakes again.

In the academic year 2006-2007 a statement related to written technical reports was included in the questionnaire (Question 7-20). The average of the second semester (4,38) was significantly higher than the mean value of the first project 3,88). This indicates the gradual building up of competencies: students gradually understand more about writing scientific reports.

Question 7-20. The tutors explain the criteria for a good scientific report. *Overall mean 4,11 (s.d. = 1,11; n = 709). This question was only used in the academic year 2006-2007, and there was a main effect from the semester. The average of the second semester was significantly higher.*



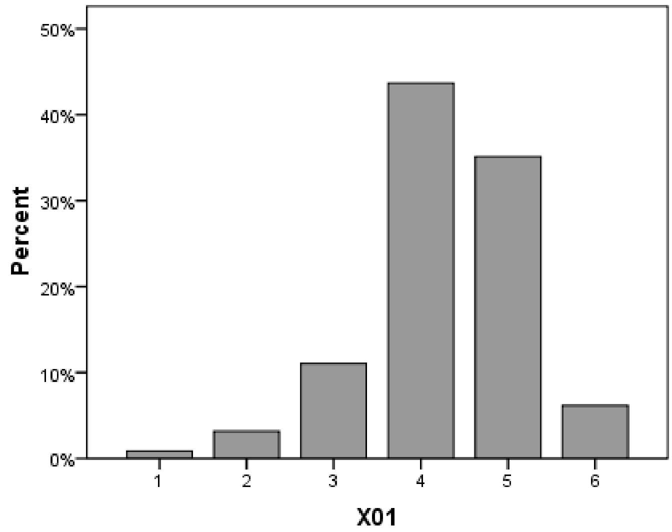


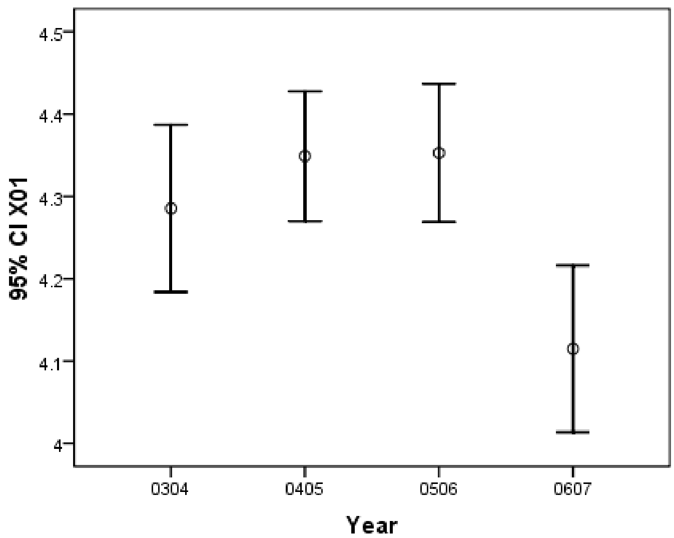
7.1.4.2 Teamworking skills

During the course a lot of attention goes to efficient team functioning. The main focus is on three parts of teamwork: dividing a team into subteams, the roles of project manager and secretary and organising efficient team meetings. The questionnaires of the first semester included statements to verify if students feel they learnt about these competencies. All these statements were only part of the questionnaires of the first semester.

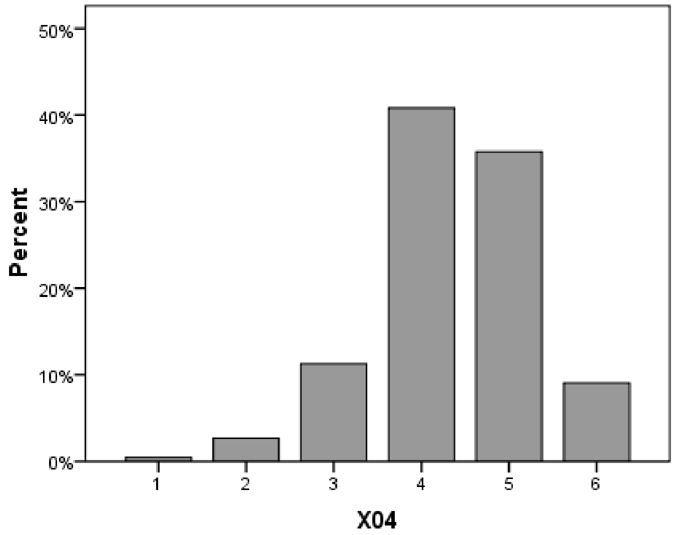
The majority of the students agree to have learned to work in a team (84 %; Question 7-21). For most of the sub-competencies about efficient team functioning the mean values were lowest in the academic year 2006-2007 (Question 7-22, Question 7-23 and Question 7-24). In this year a new technological theme was implemented so a lot of attention went to the content of the assignments. Furthermore a member of the didactic team was on pregnancy leave. She had to be replaced by two part time co-workers, so some of the teams did not have a fixed tutor for the whole semester.

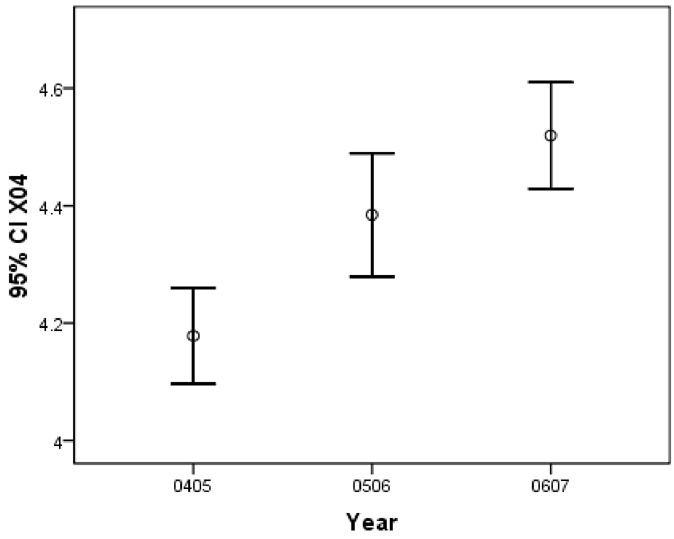
Question 7-21. Through the group project, I learned how to work efficiently within a team. *Overall mean: 4,27 (s.d. = 0,92; n = 1512). This statement was only part of the questionnaires of P&O1. There was a significant effect of the academic year. The mean for the year 0607 was significantly lower than all the others. This was the first implementation year of the new technological theme energy and a lot of attention went to the content of the assignments. Furthermore one of the tutors was replaced by two part time co-workers during her pregnancy leave.*



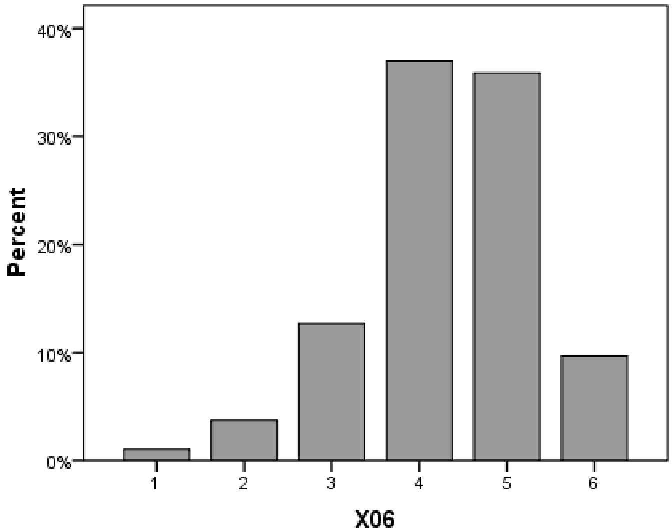


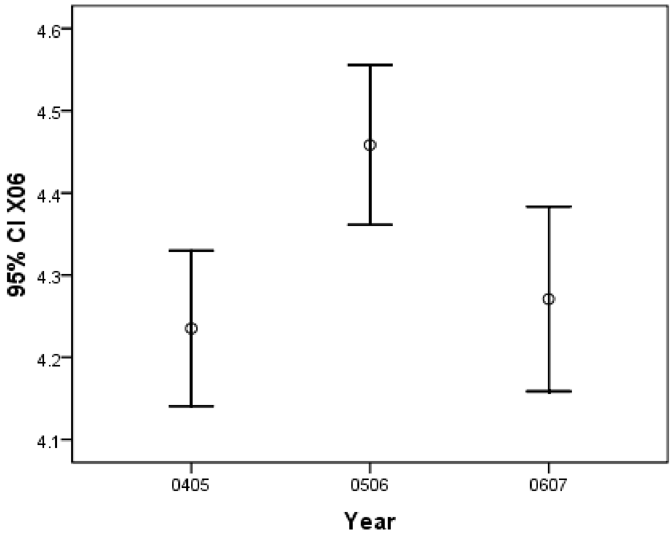
Question 7-22. Through the group project, I learned how to divide a team efficiently into subteams. Overall mean 4,36 (s.d. = 0,92; n = 1127). There was a significant effect of the academic year: the average of 0607 was significantly higher than 0506, which was in its turn significantly higher than 0405.



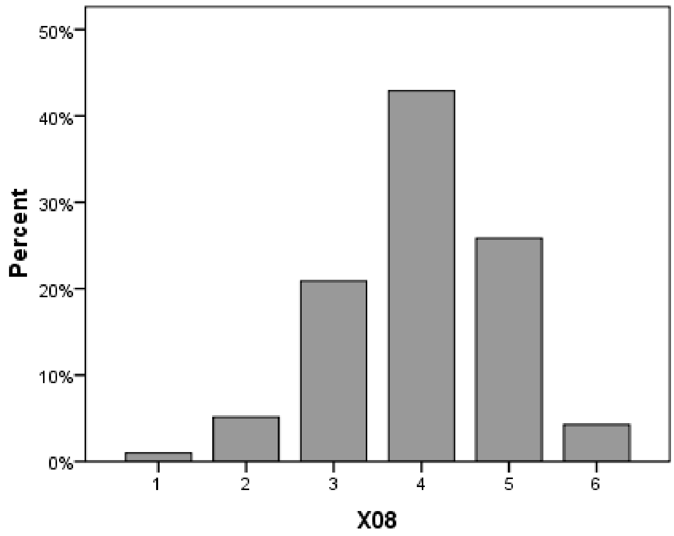


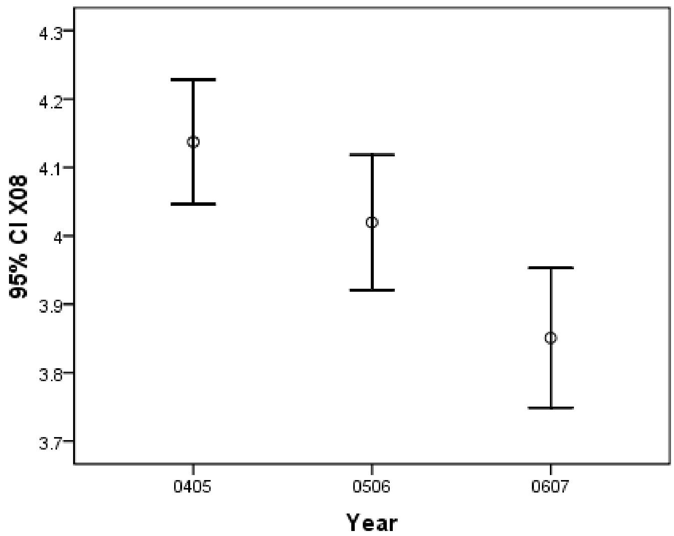
Question 7-23. Through the group project, I learned about the roles of project manager and secretary of a team. *Overall mean 4,32 (s.d. = 1,01; n = 1127). The mean of 0506 was significantly the highest.*





Question 7-24. Through the group project, I learned how and when to organise efficient team meetings. Overall mean 4,00 (s.d. = 0,97; n = 1126). The mean of 0607 was significantly the lowest of all.





7.1.5 Organisation of the course

7.1.5.1 Gradual building up of competencies

For the P&O courses there was opted for a gradual approach in confronting students with technical and social skills. Within a semester instruction seminars accompanied by exercises give each individual student the opportunity to master technical skills. In the project work that follows, the students need to apply these competencies together with the gradual building up of social skills. During the second semester, students build upon their experience of the first semester for competencies like systematic problem solving, teamwork, experimenting, communication skills, ...

In a meeting with first year students that was organised in the middle of the second semester of 2006-2007, students indicate they like the more open character of P&O2. This gives them the freedom to experiment and be on the wrong track for a while.

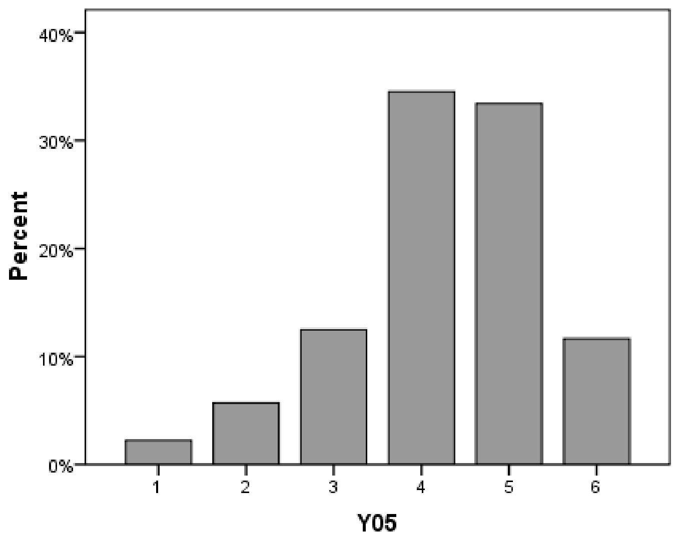
Towards the third semester, the assignments are more complex and the students become more self-responsible for their work. Mastering the necessary competencies during the first and second semester prepares them for the open end design project

Within a semester

80 % of the students agree to have used the technical skills that are taught in lectures and exercises (Question 7-25).

In the interviews that were organised, the students often indicated that they lack the necessary skills to use the Maple software efficiently during the teamwork. Learning to use this software is the subject of one instruction seminars and two exercises in the first semester. To meet these complaints, the mini-library in the design room now contains reference books of the Maple software. Furthermore the assignments contain extra tips for the maple calculations. Especially in the first semester, templates in Maple help the students to learn the software.

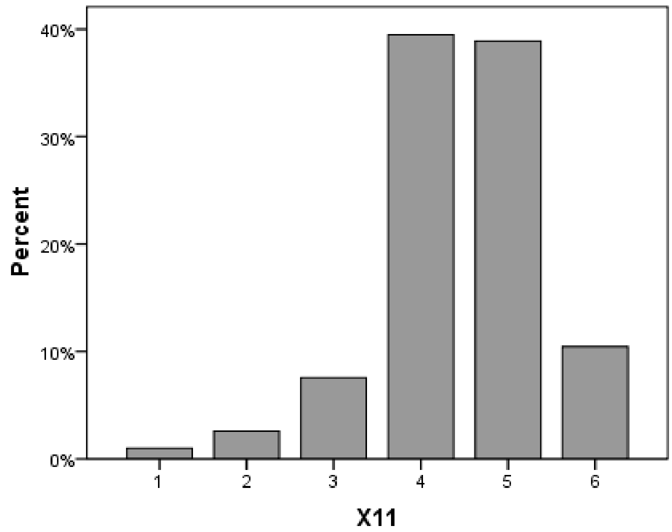
Question 7-25. Working on the team project, I applied the knowledge and skills I learned during the instruction seminars and exercises. *Overall mean 4,26n (s.d. = 1,13; n = 2242).*



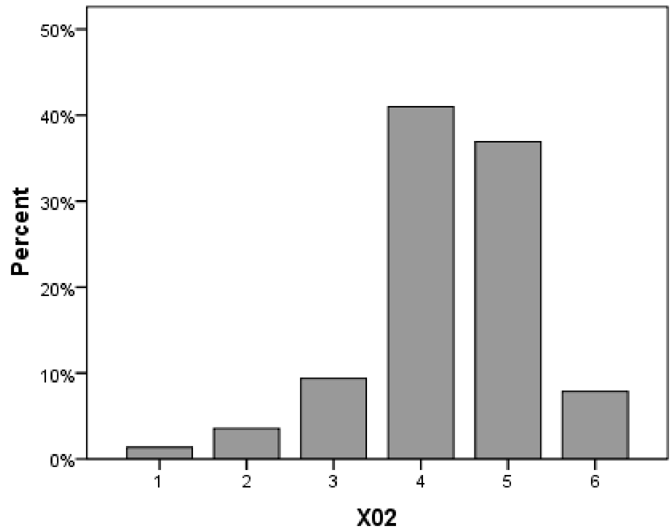
From the first project to the project of the second semester

In the questionnaires of the second semester, students were asked if they had learned more about systematic problem solving and teamworking skills, in comparison of the first project. Students respond positively and confirm the learning improvement (Question 7-26, Question 7-27, Question 7-28, Question 7-29 and Question 7-30). For none of the statements a significant effect of the academic year was found.

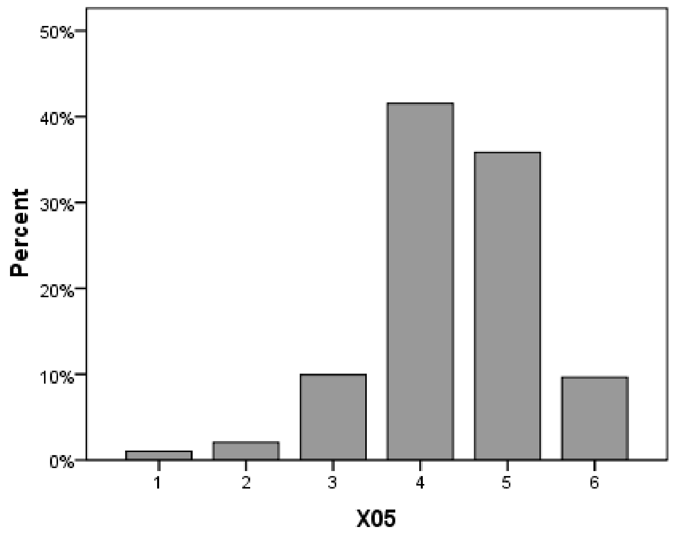
Question 7-26. Through working on the second project, in comparison with the first semester, I now understand more about a systematic approach to solve problems. *Overall mean 4,44 (s.d. = 0,94; n = 689).*



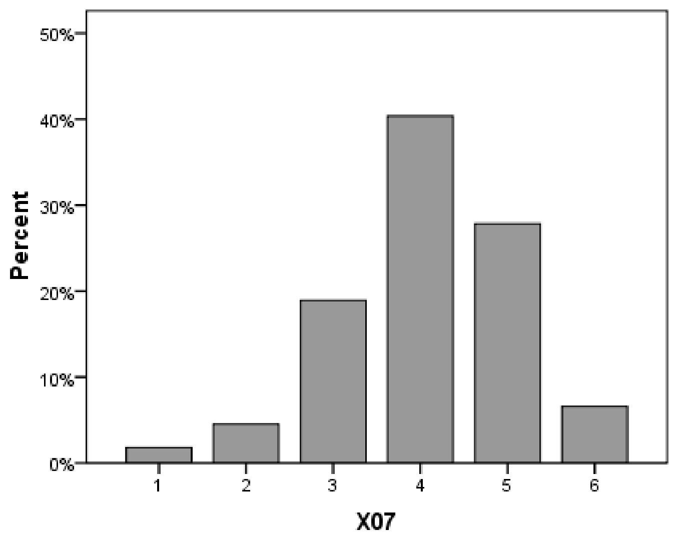
Question 7-27. What I learned in the first group project about efficient group functioning, helped to get a good result in the second project. *Overall mean 4,32 (s.d. = 0,97; n = 737).*



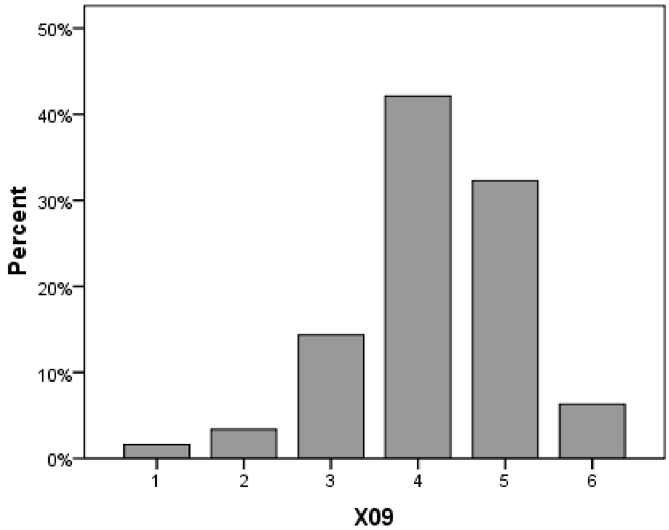
Question 7-28. Through working on the second project, in comparison with the first semester, I now understand more about dividing a team efficiently into subteams. *Overall mean 4,38 (s.d. = 0,94; n = 1067). 87 % of the students agreed upon the statement.*



Question 7-29. Through working on the second project, in comparison with the first semester, I now understand more about the roles of project manager and secretary of a team. *Overall mean 4,08 (s.d. = 1, 03; n = 1063). 75 % of the students agreed upon the statement.*



Question 7-30. Through working on the second project, in comparison with the first semester, I now understand more about organising efficient team meetings. Overall mean 4,19 (s.d. = 0,98; n = 1066). 81 % of the students agreed upon the statement.



Preparation for the project of the third semester

At the end of the third project, the students filled out a questionnaire. They were asked whether what they had learned in the first and second semester helped them for completing the third design project, which has an open end (Question 7-31, Question 7-32, Question 7-33, Question 7-34 and Question 7-35).

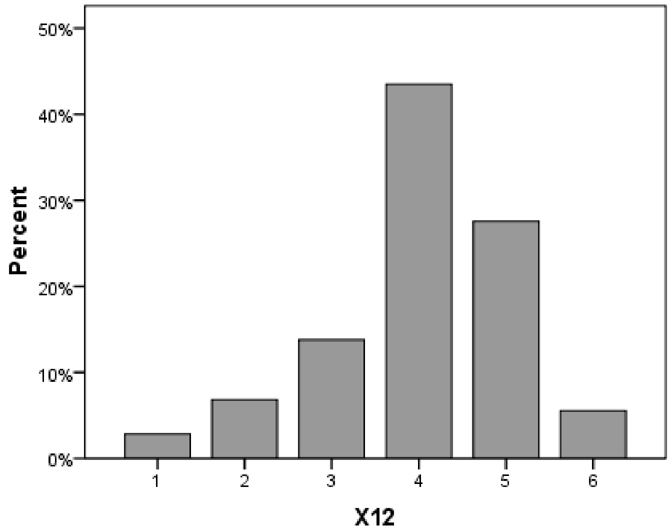
Statements were included about several skills: systematic problem solving, team functioning, communication skills, planning of a project and experimenting. Students find what they learned about systematic problem solving most useful (overall average of 4,03), and what they learned about performing a scientific experiment did not help them much (overall average of 2,89).

For two of the statements the results after the first implementation year were significantly the lowest. The learning track improved by the use of an integrated textbook. That way the students were more informed about the course concepts and got a detailed description of the objectives.

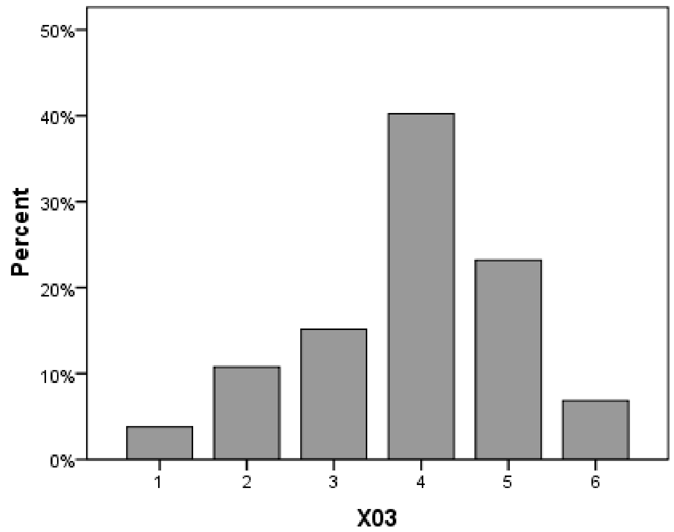
This however needs further attention. During the academic year 2008-2009 more attention went to a detailed briefing of the didactic team involved in the organisation of the third project.

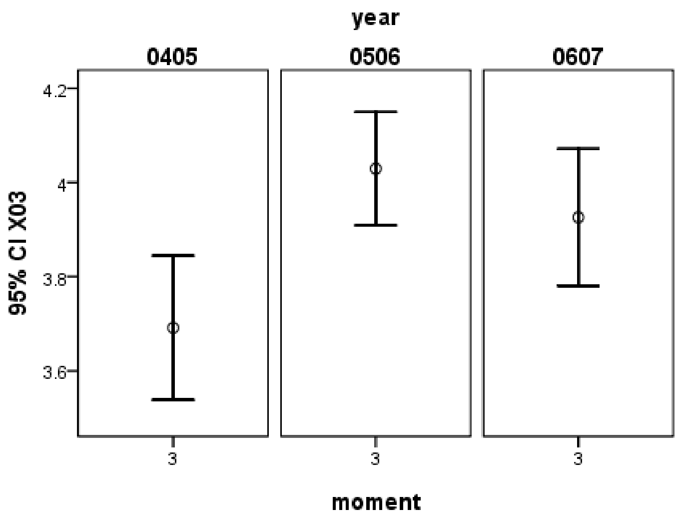
Most of the professors of the didactic team of ‘Problem Solving and Engineering Design’ are involved in the organisation of the course in the first three semesters of the bachelor. They evaluate the students’ project work in all three semesters. It is their subjective qualitative impression that the students benefit from the gradual building up of competencies. The students gradually become more independent team workers who manage their own project and present their work properly, written as well as oral.

Question 7-31. What I learned in the team projects of the first and second semester about systematic problem solving, helped to get a good result on the project of the third semester. *Overall mean 4,03 (s.d. = 1,08; n = 849).*

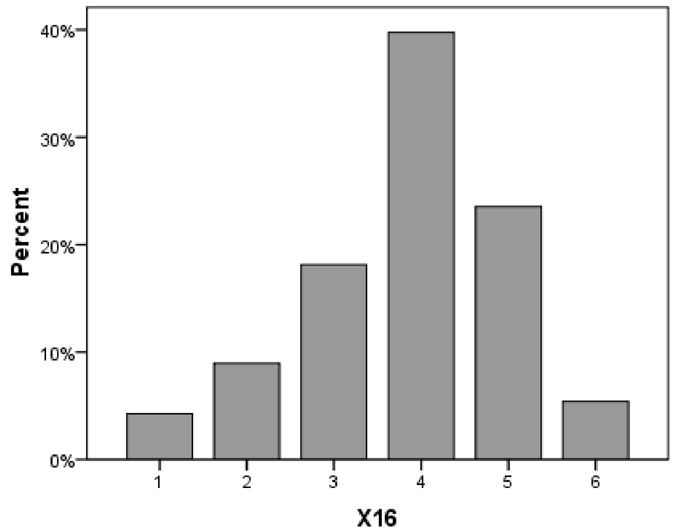


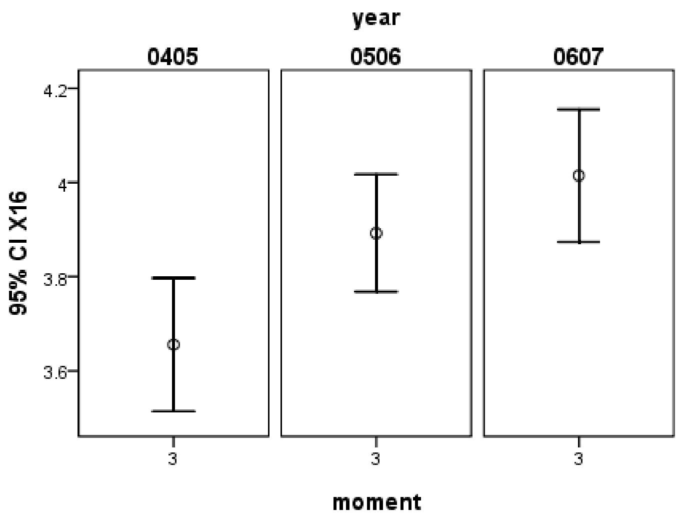
Question 7-32. What I learned in the team projects of the first and second semester about team functioning, helped to get a good result on the project of the third semester. *Overall mean 3,89 (s.d. = 1,19; n = 845). There was a significant effect of the academic year. The average result after the first implementation year was significantly the lowest (3,69; s.d. = 1,27; n = 269).*



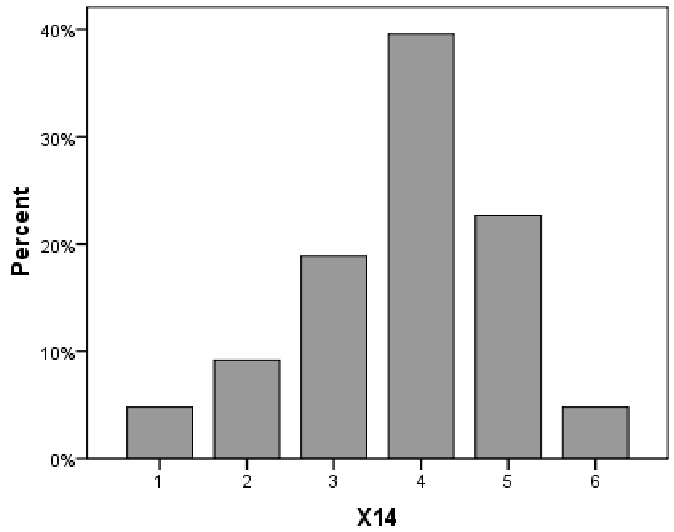


Question 7-33. [What I learned in the team projects of the first and second semester about written and oral communication, helped to get a good result on the project of the third semester.] *Overall mean 3,86 (s.d. = 1,16; n = 850). There was a significant effect of the academic year. The average result after the first implementation year was significantly the lowest (3,65; s.d. = 1,18; n = 270).*

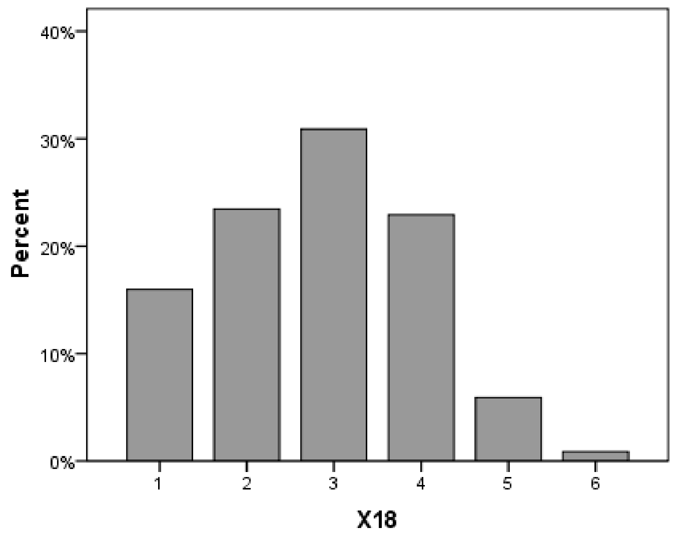




Question 7-34. What I learned in the team projects of the first and second semester about project planning, helped to get a good result on the project of the third semester. *Overall mean 3,81 (s.d. = 1,17; n = 851).*



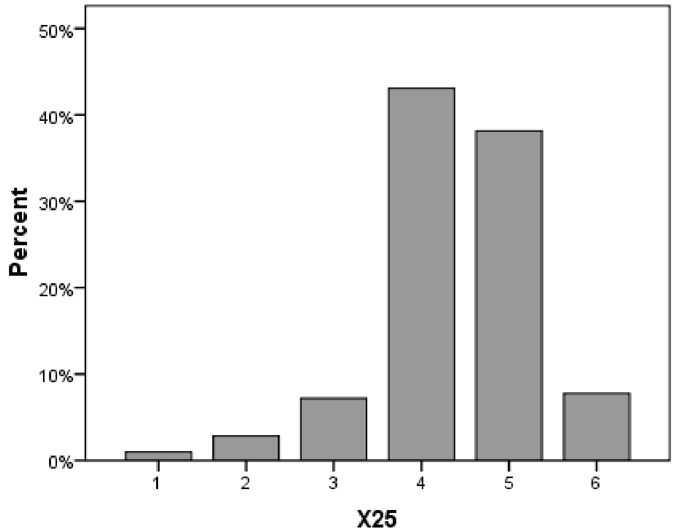
Question 7-35. What I learned in the team projects of the first and second semester about performing a scientific experiment, helped to get a good result on the project of the third semester. *Overall mean 2,89 (s.d. = 1,18; n = 576).*



7.1.5.2 Active learning

One of the objectives of the course is to introduce the first year students into real engineering practice. The project is as hands on as possible. Students appreciate this and 89 % participates actively (Question 7-36).

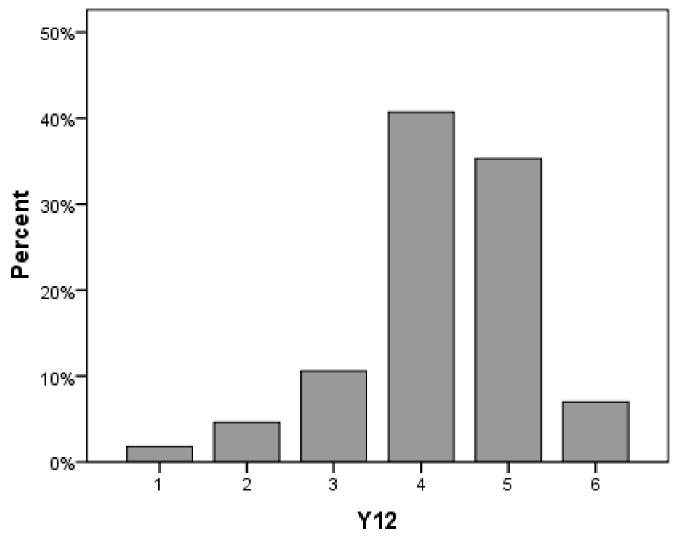
Question 7-36. The way the teamwork is organised, motivates me to participate actively. Overall mean 4,38 (s.d. = 0,91; n = 708). This statement was only included in the questionnaire of the academic year 2006-2007. There was no significant difference between P&O1 and P&O2.

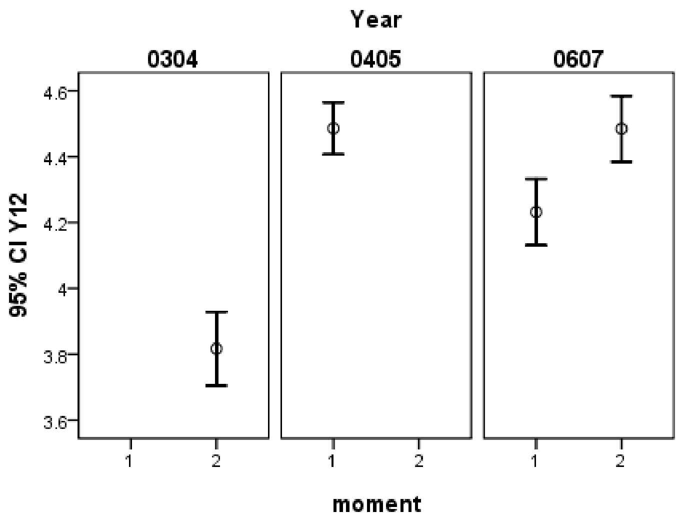


7.1.5.3 Practical organisation

In total 83 % of the interrogated students agreed the course was well organised (Question 7-37). The values for the first implementation year were significantly lower, which is not surprising. Also the average for P&O2 is significantly lower than the first semester. This is also understandable, because of the more open character of the second project.

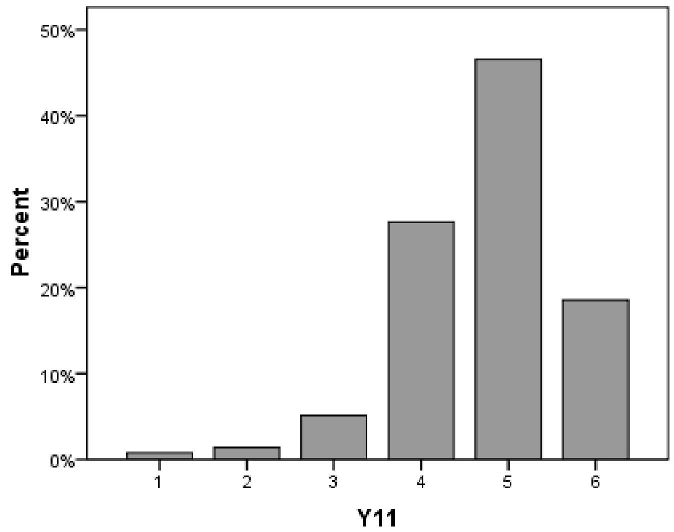
Question 7-37. *The course was well organised.* *Overall mean 4,42 (s.d. = 1,01; n = 1499). The effect from the semester and the academic year were both significant. For P&O1, data was gathered in the academic years 2006-2007 (4,23; s.d. = 1,00; n = 380) and 2004-2005 (4,49; s.d. = 0,79; n = 387). The value for 2004-2005 is significantly higher. For P&O2 there is data from 2003-2004 (3,81; s.d. = 1,15; n = 404) and 2006-2007 (4,48; s.d. = 0,91; n = 324). Again the latter is significantly higher. This is not surprisingly because 2003-2004 was the first the course was organised. And the average for the first semester is significantly higher than of the second project, which is formulated more open.*

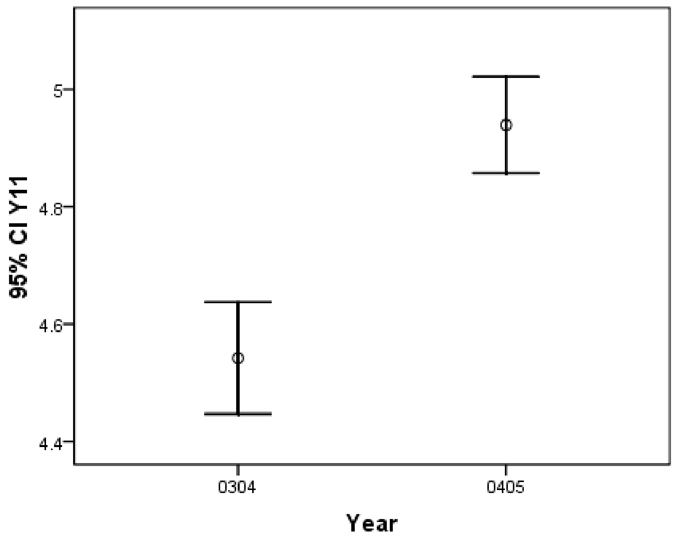




After the first semester the majority of the students agree that the design studios have all the necessary equipment to complete the project well (Question 7-38). This also improved significantly from the first implementation year to the second.

Question 7-38. [The design room has all the necessary equipment to complete the team assignments.] *Overall mean 4,73 (s.d. = 0,92; n = 782). This statement was only included in the questionnaires of the second semester. The average of the academic year 2004-2005 (4,94; s.d. = 0,81; n = 378) is significantly higher than the average of the first implementation year 2003-2004 (4,54; s.d. = 0,97; n = 404).*

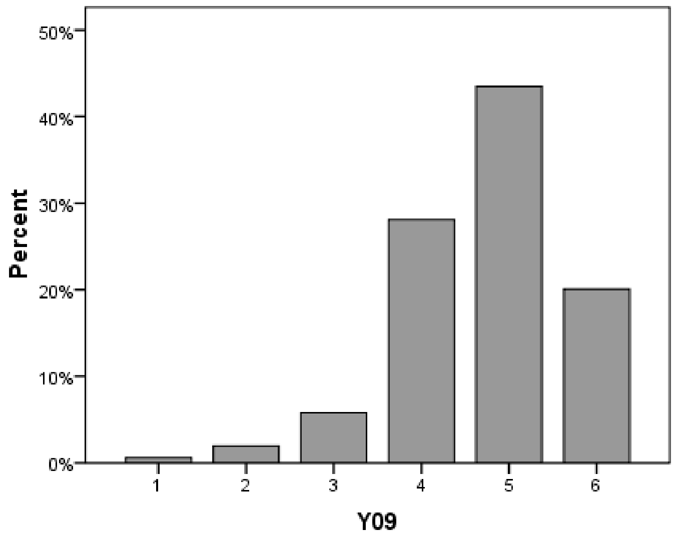


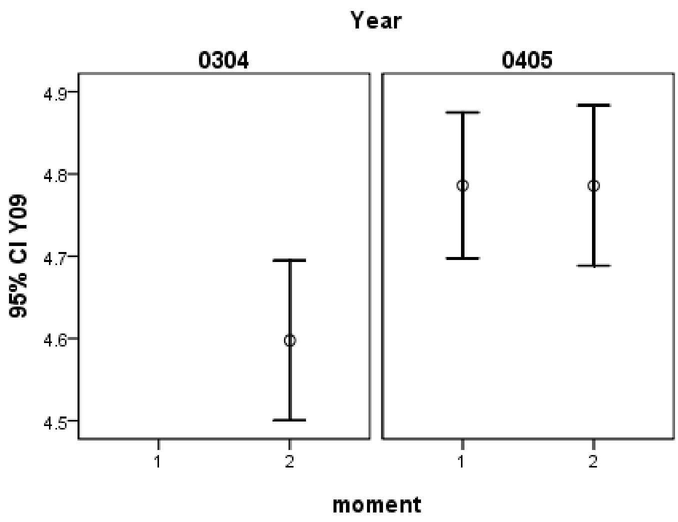


Teams are formed randomly by the didactic team. And there are formed new teams after every project. Students often like to stay working with their team members when the atmosphere within a team is pleasant. The teams are mixed to encourage the students to learn from other experiences and to start the new semester with a clean slate.

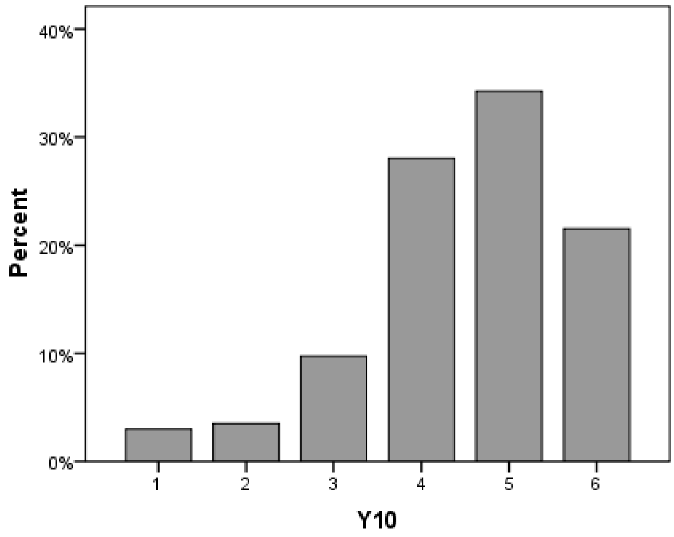
Most of the students agree upon the randomly formed teams and the formation of new teams at the beginning of the second semester (Question 7-39 and Question 7-40). For both statements there is a significant effect of the academic year. The average in 2004-2005 is significantly higher than in the first implementation year (2003-2004). Probably more attention went to explaining the reasoning behind the team formation to the students.

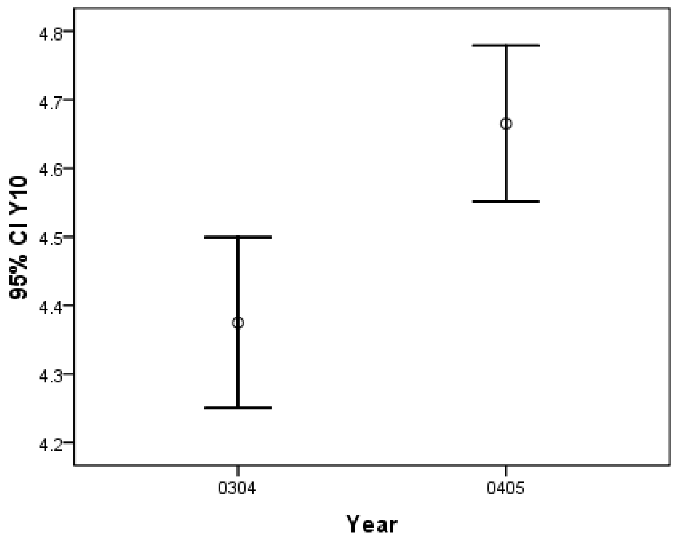
Question 7-39. [Randomly formed project groups are acceptable.](#) *Overall mean 4,72 (s.d. = 0,95; n = 1171). There is a significant effect of the academic year. For the second project, the average in 2004-2005 (4,79; s.d. = 0,93; n = 766) is significantly higher than in the first implementation year (4,60 (s.d. = 0,99; n = 386) in 2003-2004). Probably more attention went to explaining the reasoning behind the team formation to the students.*





Question 7-40. <u>The formation of new teams at the beginning of the second semester is acceptable.</u> *Overall mean 4,52 (s.d. = 1,20; n = 771). This question was only asked at the end of the second semester. There was a significant effect of the academic year. The average in 2004-2005 (4,66; s.d. = 1,12; n = 376) is significantly higher than in the first implementation year (4,37 (s.d. = 1,26; n = 395) in 2003-2004). Probably more attention went to explaining the reasoning behind the team formation to the students.*





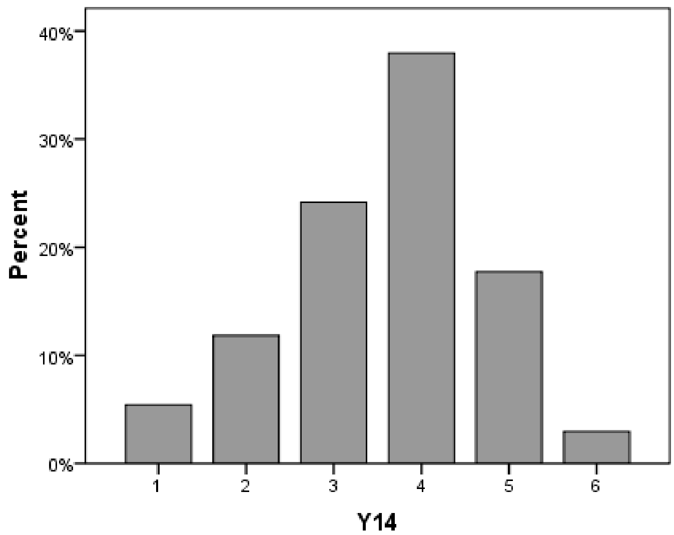
7.1.5.4 Clearness of the assignments

59 % of the students agreed that it was always clear for them what was expected for the P&O course (Question 7-41). Especially during the lectures, students find it difficult to understand what they should do with it. The speakers always emphasise the purpose of the lecture.

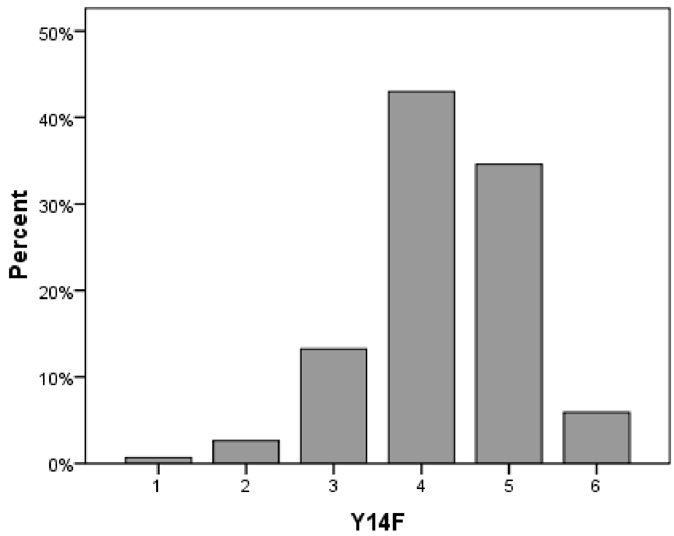
Since the academic year 2005-2006 a manual is published with all generic documents and guidelines for the generic skills. This manual also clearly states what is expected from the students during the different learning activities. These guidelines are also part of the introductory lecture in the beginning of the semester.

Since the academic year 2006-2007 a coloured time schedule visualises the different assignments and deadlines of the first semester.

Question 7-41. It was always clear to me what was expected from me for this course. Overall mean 3,60 (s.d. = 1,16; n = 406). When there are lectures, students find it more difficult to really know what they are expected to do. After the first implementation year during every lecture it was emphasised what was the purpose of it and also the manual of P&O described the objectives of the different didactic forms.

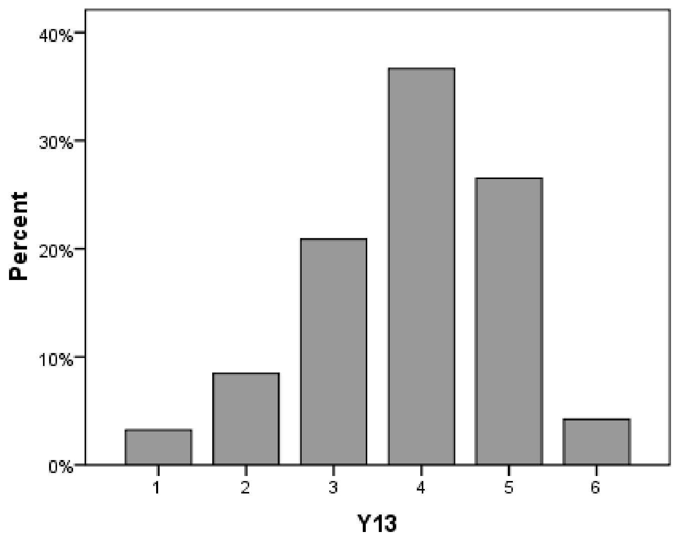


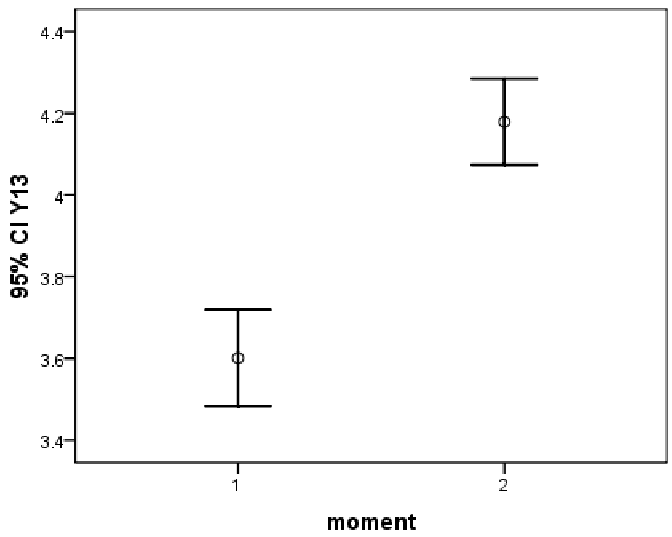
Question 7-42. For the question if it was clear what was expected during the team assignments*, the overall mean is 4,30 (s.d. = 0,90; n = 763). There was no significant difference between the two semesters. 83 % of the students agree with this statement.*



During the teamwork, more students now what is expected (Question 7-42). Especially in the second semester the majority agrees the assignments are formulated clearly (Question 7-43). For teams of eight students to work together at the same time the assignments are extensive. Especially in the first semester a lot of extra tips about the way to solve the problem and the team functioning are included in the assignments. Also the work load needs to remain high enough, especially in the beginning of the first semester. Therefore the assignments are extensive and sometimes require a long time reading. In the hearing that was organised at the end of the academic year 2006-2007, the students indicate they feel to lose a lot of time by reading the instructions. The experience of the didactic team is that most of the students do not read them well and ask their tutor later extra questions. This is a problem because the amount of guidance is limited to three tutors for 12 to 14 teams of eight students.

Question 7-43. The assignments are formulated clearly. *Overall mean 3,87 (s.d. = 1,12; n = 709). This statement was only included in the questionnaires of the academic year 2006-2007. The average result for the second semester (4,18; s.d. = 0,97; n = 324) was significantly higher than for the first semester (3,60; s.d. = 1,17; n = 381). For teams of eight students to work together at the same time the assignments are extensive. Especially in the first semester a lot of extra tips about the way to solve the problem and the team functioning are included in the assignments. Also the work load needs to remain high enough, especially in the beginning of the first semester.*





7.1.5.5 Time budget

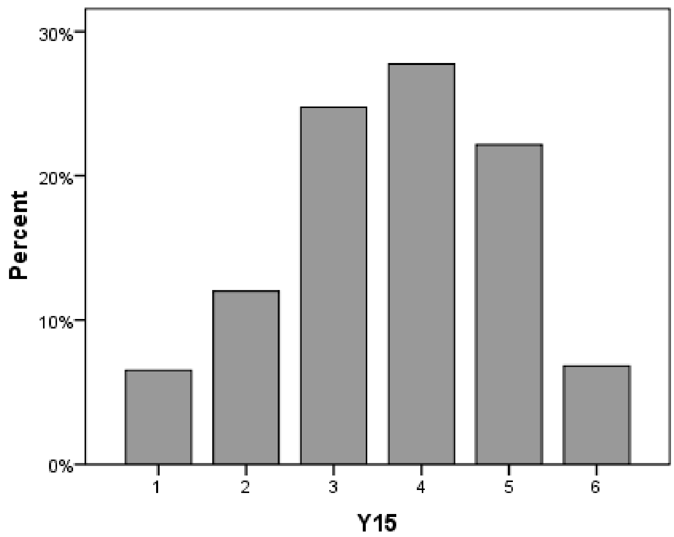
In total 57 % of the students feel there was sufficient time provided in the design room the complete the team assignments (Question 7-44). This is rather low.

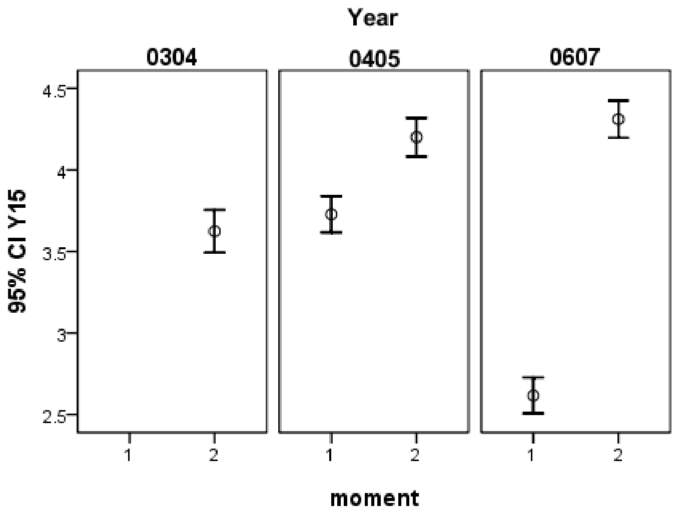
Moreover the average results for the first semester are significantly lower than the ones for the second semester. For a part this is deliberately done by the didactic team. In the first semester, certainly during the first team sessions, the work load is deliberately made quite high.

Question 7-44. There was sufficient time provided in the design room to complete the team project. *Overall mean 3,86 (s.d. = 1,36; n = 706). There was a significant effect from the semester as well as the academic year.*

For both the academic years 2004-2005 and 2006-2007 the average of the second semester was significantly higher than the one of the first semester. Especially the average result of the first semester in 2006-2007 is really low (2,62; s.d. = 1,10; n = 380). This can be explained by the fact that 2006-2007 was the first implementation year for the new technological theme energy, and one of our tutors was on pregnancy leaf, so the guidance of the students was far from optimal in that first semester. Furthermore, in the first semester, certainly during the first team sessions, the work load is deliberately quite high.

For P&O1 the average of the academic year 2004-2005 is significantly higher than the one of 2006-2007. For P&O2 there is no significant difference between 2004-2005 and 2006-2007. The result for 2003-2004, which was the first implementation year, is significantly the lowest.

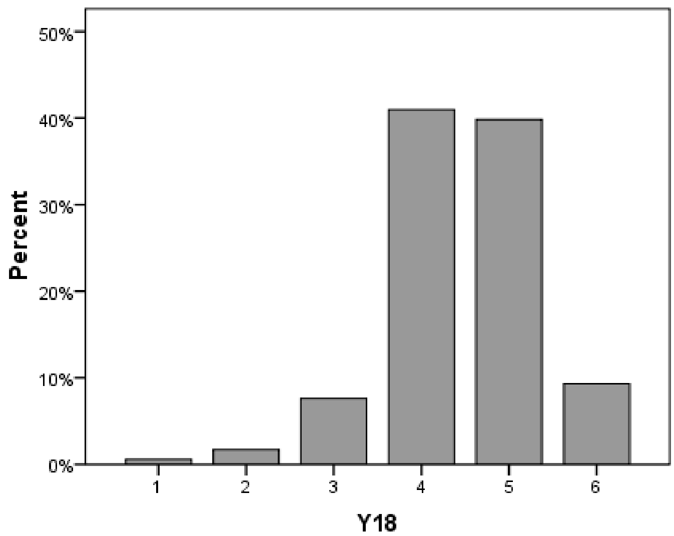




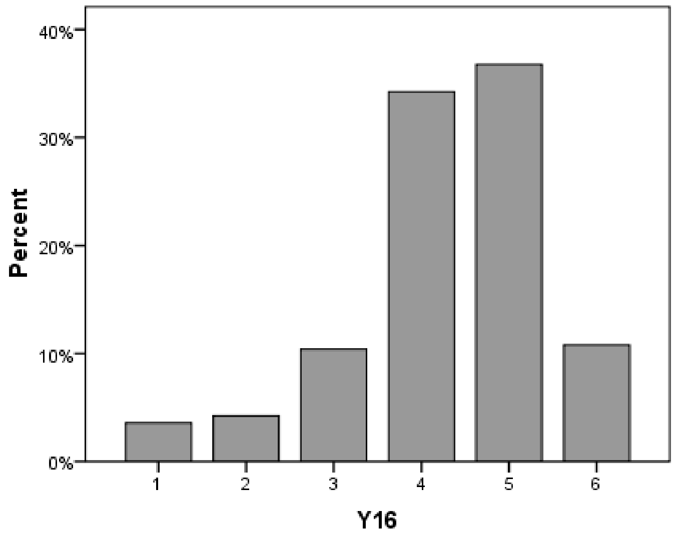
7.1.5.6 Student marking

Peer assessment is used for the evaluation of individual contributions to the group assignments. The majority of the students think this is a fair method and considers peer assessment to be a valuable evaluation tool (Question 7-45 and Question 7-46). This was also confirmed during the hearing that was organised at the end of the academic year 2003-2004.

Question 7-45. The way the mark is distributed among the team members is fair. *Overall mean 4,48 (s.d. = 0,87; n = 708). This statement was only part of the questionnaire in the academic year 2006-2007. There is no significant effect of the semester.*



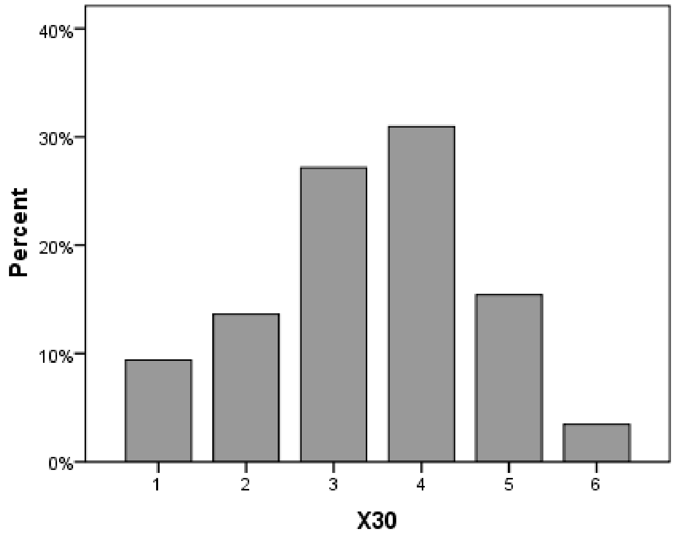
Question 7-46. Peer assessment is a valuable tool to evaluate the individual contribution of team members in group projects. Overall mean 4,29 (s.d. = 1,15; n = 2203).

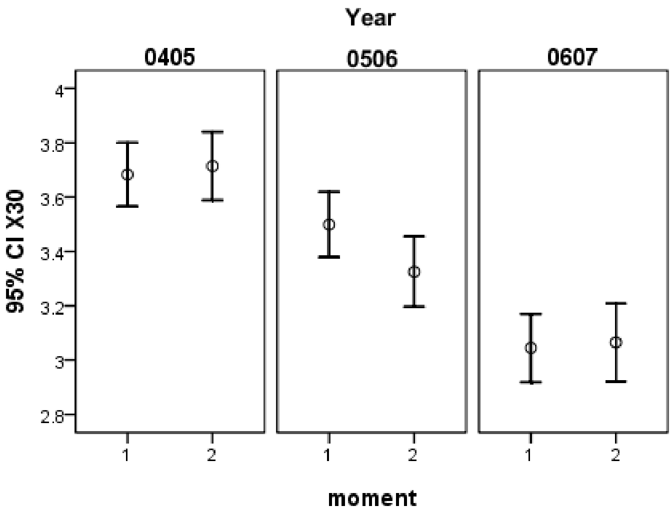


Because peer assessment forces students to reflect upon their skills and progress, it offers a great learning opportunity. But not all students confirm to believe that completing the peer assessment form contributes to the development of their teamworking skills (Question 7-47). The feedback obtained from the formative peer assessment offers an additional evaluation of their functioning in the team. 76 % of the students think this formative feedback is useful (Question 7-48).

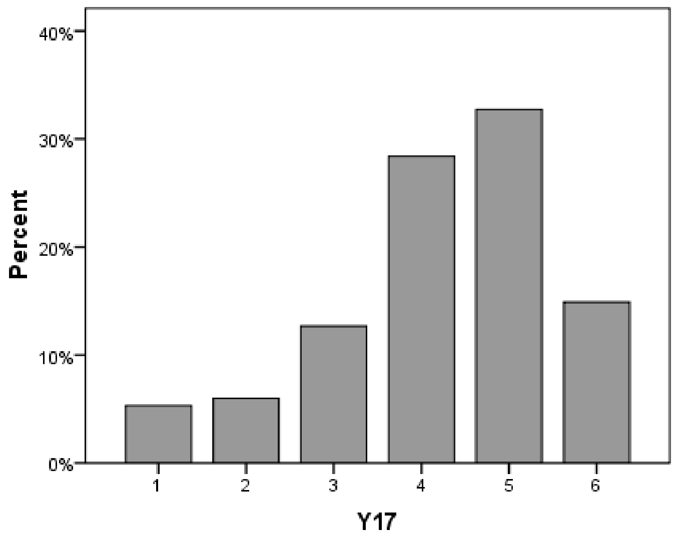
In the academic year 2006-2007 significantly fewer students agree upon the learning effect of this peer assessment. Possibly less attention went to the individual explaining of the usefulness of peer assessment to improve their own team functioning.

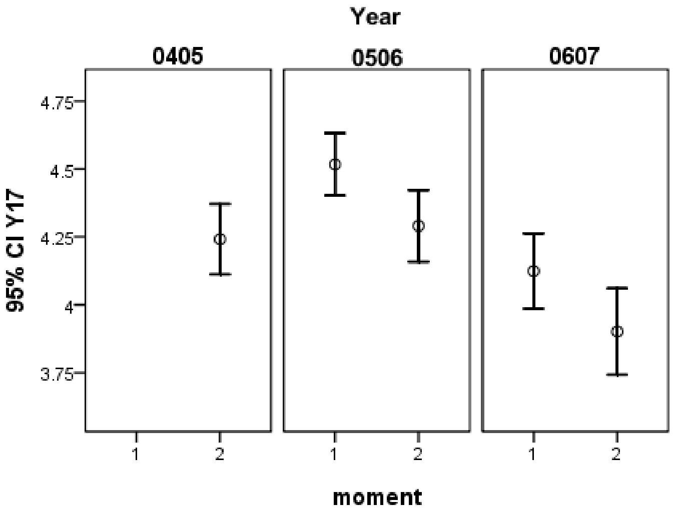
Question 7-47. Completing the peer assessment form contributed to the development of my teamworking skills. *Overall mean 3,40 (s.d. = 1,26; n = 2206). There is a significant effect from the academic year, not for the semester. For semester 1 as well as semester 2 the mean for 0405 is significantly higher than 0506, which is in his turn significantly higher than 0607. Possibly less attention went to the individual explaining of the usefulness of peer assessment to improve their own team functioning.*





Question 7-48. The formative peer assessment and feedback are useful. *Overall mean 4,23 (s.d. = 1,31; n = 1806). There is a significant effect of the semester and the academic year. For both semesters the average value of the academic year 2006-2007 is significantly the lowest. For the academic years in which this question was asked in both semester (2005-2006 and 2006-2007), the average value for the second semester was significantly the lowest. This can again be explained because of most effort in explaining the purpose of peer assessment as well as a good team spirit and team functioning is done in the first semester and less attention went to the team functioning in 2006-2007.*





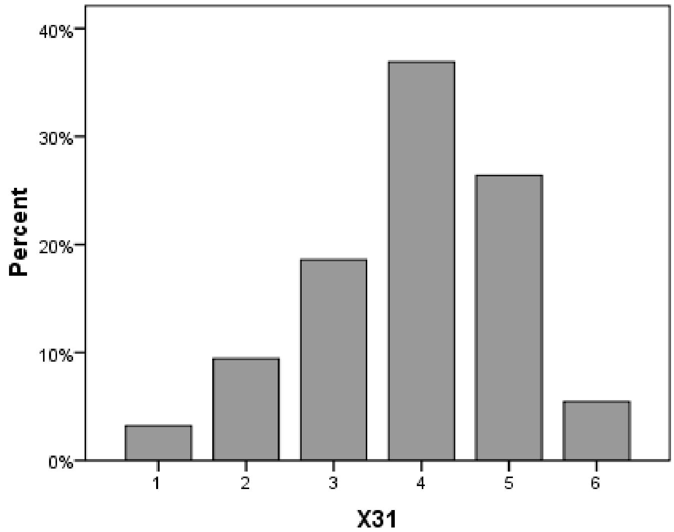
7.1.5.7 Guidance of the students

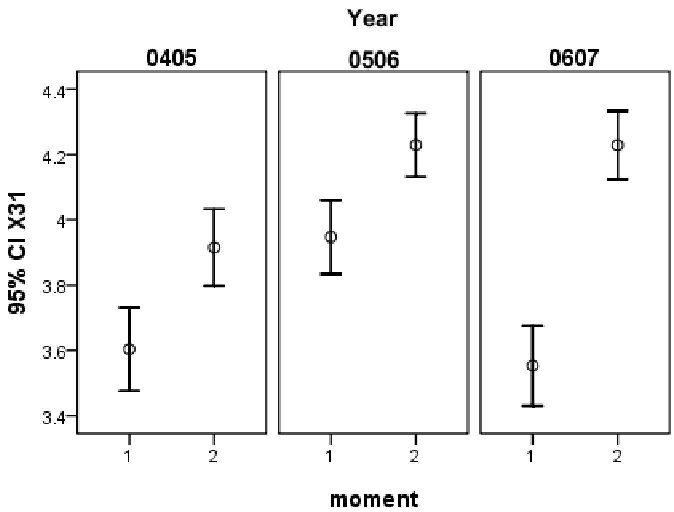
The team activities are facilitated by three tutors and two course specialists per fifteen teams of eight students. The didactic team as well as the students feel that this is the absolute minimum for a proper functioning (Question 7-49). The students find it difficult to realise that tutors do not provide ready-made answers. However, this is implicitly comprised in the course definition: the assignments emphasise self-support and students are confronted with open-end projects. After the first implementation year, the coaching was organised more efficiently by using 'fixed meetings with the tutor' and a reservation list for the course specialists in the second semester.

During the hearing that was organised at the end of the first implementation year (2003-2004) students indicate they appreciate it to have a fixed tutor for each team.

At the end of the academic year 2006-2007, students complained in the interview about the lack of technical staff. The design assignment of the second semester within the 'energy' theme is more hands-on than the rocket-assignments. More teams use tools they are not really familiar with. Technical staff and a workshop are not redundant.

Question 7-49. My team could sufficiently rely on tutors and course specialists to complete the team project with a good result. *Overall mean 3,90 (s.d. = 1,15; n = 2195). There was a significant effect of the semester as well as the academic year. For all years the average of P&O2 was significantly higher than P&O1. For the first semester project, the mean for the academic year 2005-2006 was significantly higher than the others. For the second semester project the academic year 2004-2005 was significantly lower than the others. (This question was not part of the questionnaire in the first implementation year 2003-2004.)*





7.2 Guidance and perceived learning effect

Table 7-3. Overview of the guidance items, corresponding mean scores (minimum 1, maximum 6), standard deviations and component loadings.

SCALE				ITEM			
		Number of items	**Cronbach's Alpha**		**Mean sore**	**Standard deviation**	**Factor loading**
CB1	Tutor guidance of team learning and cooperation	8	0,90	The tutor encourages us to listen to each other,	4,21	0,92	0,77
				The tutor encourages us to respect each others opinion.	4,38	0,91	0,71
				The tuter encourages us to explain difficult subjects to our team members.	4,01	0,97	0,69
				The tutor encourages us to discuss ideas within the team.	4,13	0,91	0,68
				The tutor motivates our team to look for sollutions independently.	4,54	0,81	0,67
				The tutor encourages us to learn with and from each other.	4,18	0,93	0,66
				The tutor thinks the team functioning is important.	4,32	0,87	0,65
				The tutor makes sure that our team works methodically.	3,87	0,91	0,47
CB2	Tutor content related guidance	7	0,91	The tutor knows the content of the team assignments well.	3,87	0,91	0,81
				The tutor is professional enough to provide guidance with respect to the contents.	4,5	1,02	0,81
				The tutor is well prepared for the team sessions.	4,53	0,97	0,78
				The tutor knows the objectives of the course well.	4,71	0,88	0,73
				The feedback from our tutor is useful and constructive.	4,32	0,98	0,64
				The tutors provides ways for us to find answers on our own questions.	4,28	1,01	0,57
				The tutor encourages us to complete the assignments with a good result.	4,23	1,05	0,51
CB3	Tutor feedback both individual and group	2	0,62	The tutor formulates individual feedback for individual team members.	3,3	1,09	0,61
				The tutor indicates regularly the strenghts and weaknesses of our team.	3,53	1,09	0,58
CB4	Tutor information about objectives, expectations, evaluation	3	0,70	Enough information was supplied about the objectives and evaluation of the course.	4,13	0,93	0,75
				Enough information is supplied about the assignments and the expected results.	3,77	1,08	0,7
				The tutor explains which results are expected.	4,14	0,91	0,53
CB5	Input of course specialists	2	0,81	The contribution of the course specialists helps our teamwork progres.	4,23	1,04	0,89
				The contribution of the course specialists with respect to the content of the assignments is relevant.	4,27	1,05	0,88

Table 7-4. Overview of the items that contribute to the 'student learning' scales. These scales are constructed per semester: (a) academic year 2005-2006, semester 1 (Y3M1), (b) academic year 2005-2006, semester 2 (Y3M2), (c) academic year 2006-2007, semester 1 (Y4M1) and (d) academic year 2006-2007, semester 2 (Y4M2).

(a) academic year 2005-2006, semester 1 (Y3M1)

SCALE Y3M1				**ITEM**				
Y3M1	**Scale**	**Number of items**	**Cronbach's Alpha**	**Or. item nr.**		**Mean sore**	**Standard deviation**	**Factor loading**
C1Y3M1	Teamworking skills	4	0,72	X08	Through the group project, I learned how and when to organise efficient team meetings.	4,00	0,97	0,748
				X06	Through the group project, I learned about the roles of project manager and secretary of a team.	4,32	1,01	0,683
				X04	Through the group project, I learned how to divide a team efficiently into subteams.	4,36	0,92	0,650
				X01	Through the group project, I learned how to work efficiently within a team.	4,27	0,92	0,503
C2Y3M1	Integrative concept and relevance of P&O	2	0,63	X29	Through the teamwork I understand better the basic principles taught in the regular scientific courses.	4,01	1,09	0,809
				X28	I integrated basic principles of different regular courses to complete the team assignment.	4,80	0,89	0,790
C3Y3M1	Peer assessment	3	0,72	Y16	Peer assessment is a valuable tool to evaluate the individual contribution of team members in group projects.	4,29	1,15	0,825
				Y17	The formative peer assessment and feedback are useful.	4,22	1,31	0,770
				X30	Completing the peer assessment form contributed to the development of my team working skills.	3,40	1,26	0,736

(b) academic year 2005-2006, semester 2 (Y3M2)

SCALE Y3M2				ITEM				
Y3M2	**Scale**	**Number of items**	**Cronbach's Alpha**	**Or. item nr.**		**Mean sore**	**Standard deviation**	**Factor loading**
C1Y3M2	Gradual building up of competences	7	0,85	X05	Through working on the second project, in comparison with the first project, I now understand more about dividing a team efficiently into subteams.	4,38	0,94	0,826
				X09	Through working on the second project, in comparison with the first project, I now understand more about organising efficient team meetings.	4,19	0,98	0,798
				X11	Through working on the second project, in comparison with the first project, I now understand more about a systematic approach to solve problems.	4,44	0,94	0,753
				X07	Through working on the second project, in comparison with the first project, I now understand more about the roles of project manager and secretary of a team.	4,07	1,03	0,685
				X02	What I learned in the first group project about efficient group functioning, helped to get a good result in the second project.	4,32	0,97	0,567
				X17	The experiment we performed while working in team was a good introduction into scientific experiments.	4,59	0,96	0,557
				X22	Through the teamwork I learned how to master new information independantly.	4,16	0,88	0,455
C2Y3M2	Tranfer of competences beyond introductory seminar	2	0,87	Y07	What I learned during the introduction lecture about the design process, helped to complete the team project with a good result.	3,42	1,19	0,851
				X13	What I learned during the introduction lecture about project planning, helped to complete the team project with a good result.	3,50	1,18	0,803
C3Y3M2	Peer assessment	3	0,74	X30	Completing the peer assessment form contributed to the development of my team working skills.	3,40	1,26	0,806
				Y17	The formative peer assessment and feedback are useful.	4,22	1,31	0,777
				Y16	Peer assessment is a valuable tool to evaluate the individual contribution of team members in group projects.	4,29	1,15	0,764
C4Y3M2	Integrative concept and relevance of P&O	2	0,72	X28	I integrated basic principles of different regular courses to complete the team assignment.	4,80	0,89	0,806
				X29	Through the teamwork I understand better the basic principles taught in the regular scientific courses.	4,01	1,09	0,729

(c) academic year 2006-2007, semester 1 (Y4M1)

SCALE Y4M1				ITEM				
Y4M1	**Scale**	**Number of items**	**Cronbach's Alpha**	**Or. item nr.**		**Mean sore**	**Standard deviation**	**Factor loading**
C1Y4M1	Integrative concept and relevance of P&O	9	0,84	X24	I clearly see the relevance of the course for my engineering study.	4,78	0,94	0,742
				Y02	I am interested in the connection of theory and practice.	4,77	0,88	0,689
				Y01	Its relevance for my future profession makes this course fascinating.	4,38	1,04	0,660
				X26	The way the teamwork is organised, helps me to understand the connection between theory and practice.	4,43	0,90	0,625
				X25	The way the teamwork is organised, motivates me to participate actively.	4,38	0,91	0,624
				Y03	The course objectives are realistic at this point in my study.	4,59	0,86	0,611
				X29	Through the teamwork I understand better the basic principles taught in the regular scientific courses.	4,01	1,09	0,592
				X28	I integrated basic principles of different regular courses to complete the team assignment.	4,80	0,89	0,535
				Y05	What I learned during the instruction lecture and exercises, helped to complete the team project with a good result.	4,26	1,13	0,432
C2Y4M1	Contribution to independent learning	5	0,80	X19	Through the teamwork I learned to work more independently.	4,05	1,04	0,743
				X22	Through the teamwork I learned how to master new information independently.	4,16	0,88	0,714
				X20	Through this course I learned how to refer to relevant sources.	3,97	0,97	0,657
				X01	Through the group project, I learned how to work efficiently within a team.	4,27	0,92	0,597
				X23	During the team project, I reflected upon my activities to check whether I could improve on something.	4,21	0,90	0,494
C3Y4M1	Peer assessment	3	0,75	Y16	Peer assessment is a valuable tool to evaluate the individual contribution of team members in group projects.	4,29	1,15	0,826
				Y17	The formative peer assessment and feedback are useful.	4,22	1,31	0,752
				X30	Completing the peer assessment form contributed to the development of my team working skills.	3,40	1,26	0,706

SCALE Y4M1				ITEM				
Y4M1	**Scale**	**Number of items**	**Cronbach's Alpha**	**Or. item nr.**		**Mean sore**	**Standard deviation**	**Factor loading**
C4Y4M1	Teamworking skills	3	0,68	X04	Through the group project, I learned how to divide a team efficiently into subteams.	4,36	0,92	0,788
				X06	Through the group project, I learned about the roles of project manager and secretary of a team.	4,32	1,01	0,628
				X10	Through the group project, I learned to use a systematic approach to solve problems.	4,33	0,82	0,494
C5Y4M1	Clear assignment	3	0,56	Y13	The assignments are formulated clearly.	3,87	1,12	0,778
				X15	The tutors explain the criteria for a good scientific report.	4,11	1,11	0,693
				X31	My team could sufficiently rely on tutors and course specialists to complete the team project with a good result.	3,90	1,15	0,529

(d) academic year 2006-2007, semester 2 (Y4M2)

SCALE Y4M2				ITEM				
Y4M2	**Scale**	**Number of items**	**Cronbach's Alpha**	**Or. item nr.**		**Mean sore**	**Standard deviation**	**Factor loading**
C1Y4M2	Integrative concept and relevance of P&O	6	0,80	X26	The way the teamwork is organised, helps me to understand the connection between theory and practice.	4.43	0.90	0,720
				X25	The way the teamwork is organised, motivates me to participate actively.	4,38	0,91	0,642
				X24	I clearly see the relevance of the course for my engineering study.	4,78	0,94	0,608
				X28	I integrated basic principles of different regular courses to complete the team assignment.	4,80	0,89	0,596
				X29	Through the teamwork I understand better the basic principles taught in the regular scientific courses.	4,01	1,09	0,576
				X17	The experiment we performed while working in team was a good introduction into scientific experiments.	4,59	0,96	0,484
C2Y4M2	Gradual building up of competences	4	0,79	X05	Through working on the second project, in comparison with the first project, I now understand more about dividing a team efficiently into subteams.	4,38	0,94	0,793
				X07	Through working on the second project, in comparison with the first project, I now understand more about the roles of project manager and secretary of a team.	4,08	1,03	0,731
				X09	Through working on the second project, in comparison with the first project, I now understand more about organising efficient team meetings.	4,19	0,98	0,692
				X11	Through working on the second project, in comparison with the first project, I now understand more about a sstematic approach to solve problems.	4,44	0,94	0,684
C3Y4M2	Contribution to independent learning	4	0,74	X19	Through the teamwork I learned to work more independently.	4,05	1,04	0,683
				X20	Through this course I learned how to refer to relevant sources.	3,97	0,97	0,683
				X22	Through the teamwork I learned how to master new information independently.	4,16	0,88	0,669
				X23	During the team project, I reflected upon my activities to check whether I could improve on something.	4,21	0,90	0,624

SCALE Y4M2				ITEM				
Y4M2	Scale	Number of items	Cronbach's Alpha	Or. item nr.		Mean sore	Standard deviation	Factor loading
C4Y4M2	Tranfer of competences beyond introductory seminar	2	0,83	Y07	What I learned during the introduction lecture about the design process, helped to complete the team project with a good result.	3,42	1,19	0,841
				X13	What I learned during the introduction lecture about project planning, helped to complete the team project with a good result.	3,50	1,18	0,781
C5Y4M2	Peer assessment	4	0,65	Y16	Peer assessment is a valuable tool to evaluate the individual contribution of team members in group projects.	4,29	1,15	0,810
				X30	Completing the peer assessment form contributed to the development of my team working skills.	3,40	1,26	0,591
				Y17	The formative peer assessment and feedback are useful.	4,22	1,31	0,591
				Y18	I think that the way the marking is done among group members, is fair.	4,46	0,87	0,587
C6Y4M2	Clear assignment	2	0,52	Y13	The assignments are formulated clearly.	3,87	1,12	0,674
				X31	My team could sufficiently rely on tutors and course specialists to complete the team project with a good result.	3,90	1,15	0,626

Table 7-5. Partial regression coefficients and explained variance (R Square) for regression analyses performed per 'student learning' scale per semester ('student learning' scale = dependent variable, 'guidance' scales = independent variables).

Legend	
	scale does not exists in this semester
	signifant positve correlation (coefficient > 0,200)
	signifant positve correlation (coefficient < 0,200)
	no signifant correlation, correlation coefficient > 0
	no signifant correlation, correlation coefficient < 0
	signifant negative correlation

		SCALE				
		Integrative Concept & Relevance of P&O	Teamworking skills	Contribution to independent learning	Transfer of competen-cies beyond introductory seminar	Transfer of competen-cies beyond p&o sessions
Y3M1	2005-2006 Semester 1	C2Y3M1	C1Y3M1			
Y3M2	2005-2006 Semester 2	C4Y3M2			C2Y3M2	C1Y3M2
Y4M1	2006-2007 Semester 1	C1Y4M1	C4Y4M1	C2Y4M1		
Y4M2	2006-2007 Semester 2	C1Y4M2		C3Y4M2	C4Y4M2	C2Y4M2
Y3M1	R Square	0,238	0,219			
Y3M2	R Square	0,246			0,106	0,328
Y4M1	R Square	0,168	0,149	0,149		
Y4M2	R Square	0,261		0,167	0,140	0,207
INDEPENDENT VARIABLES	CB4	+	0,116			
	Tutor information about	0,267			+	0,282
	objectives, expectations,	0,208	0,118	0,162		
	(Cronbach alpha= 0.70)	0,339		0,208	0,127	0,141
	CB5	0,109	0,163			
	Input of course specialists	0,184			0,125	+
		0,197	0,229	0,188		
	(Cronbach alpha= 0.81)	+	+	-	+	+
	CB2	+	+			
	Tutor content related guidance	-			-	-
		-	-	-		
	(Cronbach alpha= 0.91)	-		-0,143	-0,111	-
	CB1	0,262	0,202			
	Tutor guidance of team learning	0,166			0,145	0,293
	and cooperation	0,103	0,115	+		
	(Cronbach alpha= 0.90)	0,111		0,215	0,186	0,269
	CB3	-	+			
	Tutor feedback both individual	-			+	-
	and group	-	-	+		
	(Cronbach alpha= 0.62)	-		+	+	-

7.3 Study time measurement performed during the academic year 2007-2008

This section is adapted from the written reports from DUO (Dienst Universitair Onderwijs), who performed the study time measurements together with the working group 'Evaluation of the bachelor' in the academic year 2007-2008.

7.3.1 Research question

By means of the performed study time measurement consists was examined whether there are differences between the measured and estimated study time for certain courses. Furthermore the way that students spread their study time throughout the semester could be determined.

7.3.2 Method

The study time measurement was performed using the method of time writing. For this method the students are asked to estimate on a weekly basis their study time for every course. To increase the accuracy of the measurement, the students estimate their study time separately for three different parts: (1) contact time (courses, exercises, …), (2) mandatory assignments (group assignments, papers, ...) and (3) processing of course material (studying, reading, ...).

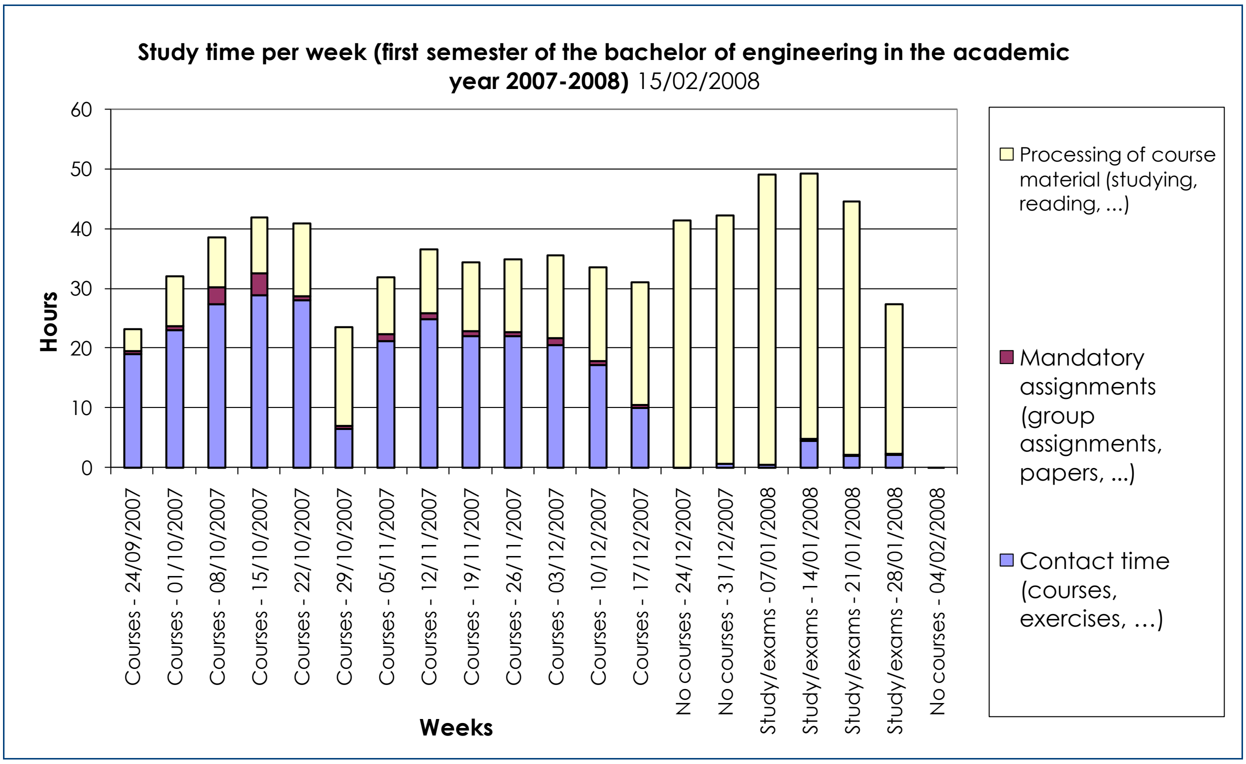
7.3.3 Results

For all courses more than ten students responded every week, so all data was included in the results. The data from all students was included (so not only of the students that passed the courses).

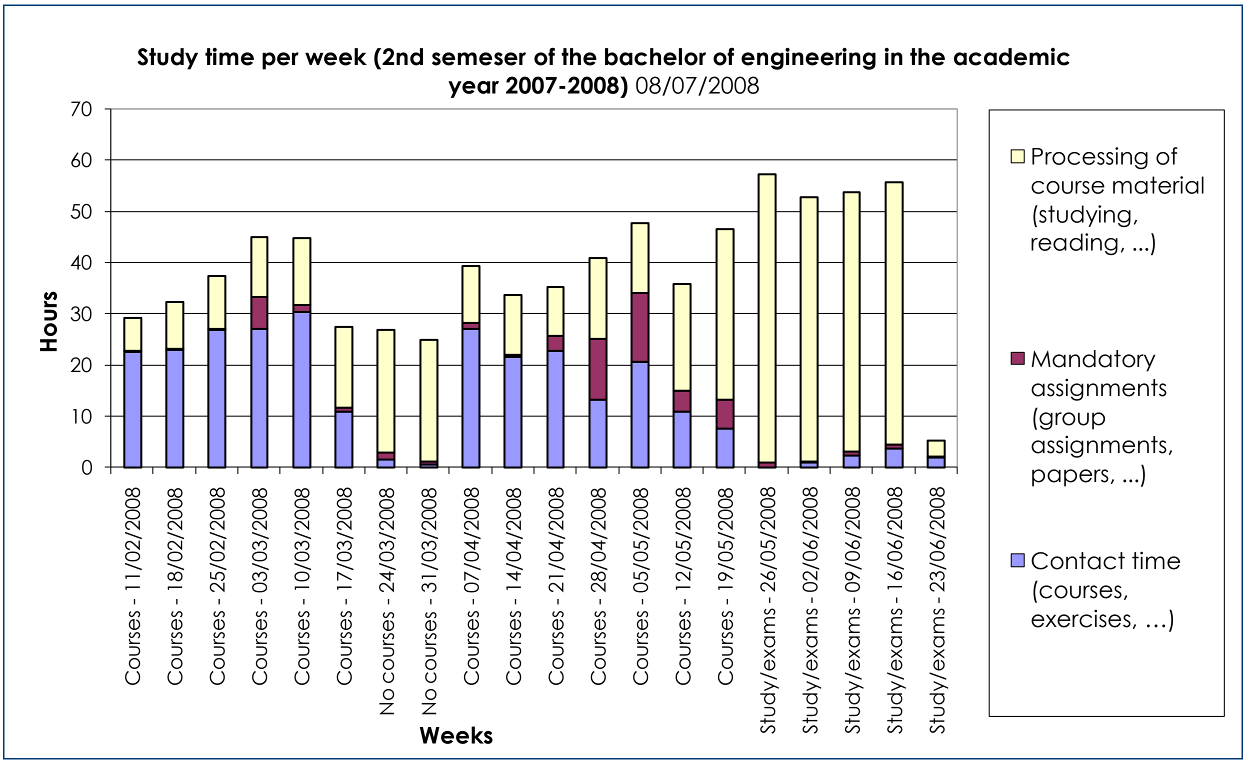
The average of the total amount of study time in the first semester of 2007-2008 was 36,5 hours and 38,7 hours in the second semester. Both are beneath the norm determined by decree (this is the amount of ECTS study points times 25 à 30 hours a week). The total study time of the first semester should be between 36,8 and 44,2 hours and for the second semester between 40 and 48 hours according to the norm.

Figure 7-1 shows the measured study time for the three parts (contact time, mandatory assignments and processing of course material) in the first and second semester of the bachelor of engineering.

Table 7-6 shows the comparison between the measured and estimated study time per course in the first year of the bachelor of engineering.



(a)



(b)

Figure 7-1. Measured study time in the first (a) and second (b) semester of the bachelor of engineering in the academic year 2007-2008.

Table 7-6. Overview of the estimated and measured study time for the courses of the first year of the bachelor of engineering.

Course	**Semester**	**ECTS credits**	**Estimated hours**	**Measured hours (average)**	**1 ECTS credit (estimated)**	**1 ECTS credit (average)**	
Problem Solving and Engineering Design, part 1	1	4	100-120	**92**	25-30	23	↓
Applied algebra	1	5	125-150	**126**	25-30	25	=
Applied mechanics, part 1	1	5	125-150	**121**	25-30	24	↓
General and technical chemistry	1	7	175-210	**178**	25-30	25	=
Calculus, part 1	1	7	175-210	**176**	25-30	25	=
Thermodynamics	2	3	75-90	**104**	25-30	35	↑
Probability calculus and statistics	2	3	75-90	**85**	25-30	28	=
Problem Solving and Engineering Design, part 2	2	3	75-90	**64**	25-30	21	↓
Philosophy	2	4	100-120	**66**	25-30	17	↓↓
Calculus, part 2	2	5	125-150	**133**	25-30	27	=
Electricity and magnetism	2	7	175-210	**183**	25-30	26	=
Methodology of information science	2	7	175-210	**139**	25-30	20	↓

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Curriculum Vitae

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